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Office of Aeronautics and
Space Technology

AIRCRAFT FUEL CONSERVATION TECHNOLOGY

TASK FORCE REPORT

September 10, 1975

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EXECUTIVE SUMMARY

Introduction

A group of government scientists and engineers drawn from NASA, DOT, FAA, and DOD was constituted as a Task Force to determine technological advancement opportunities that could result in conservation of the fuel use in air transport. For each of these opportunities a technology development program was defined and resources estimated. The impact of the implementation of this technology on air transport fuel use was estimated.

Technology Plan

The Task Force reviewed possible advances in all areas of aeronautical technology. Inputs were solicited from industry, the NASA research centers, and other government agencies. From these inputs six major programs were defined. Of these six, three are evolutionary improvements in aerodynamics, and propulsion. The three remaining programs, composite primary structures, turboprops and laminar flow control, represent attempts to develop technology that is different from that in current use in civil air transports. In several cases two levels of activity were defined for a technology element. Those activities judged to be of first priority were grouped in what is called the baseline program. Additional work judged to be important but of lower priority was also defined. These additional elements form the Level II program.

Engine Component Improvement - This effort is directed at developing improved engine components that could be used on new production of existing engine types and on newly-designed engines. Examples of such components are active clearance controls, mixers and compliant seals. The activity would also include tests of in-service engines in an attempt to determine the causes of engine performance degradation with time. These improved components are expected to be ready for use on engines produced in 1980. It is estimated that

successful development could lead to a 5 percent decrease in engine specific fuel consumption.

Fuel Conservative Engine - This propulsion activity is directed at laying the technology base for achieving higher thermodynamic efficiencies in future engine designs. It is estimated that these improvements in engines will result in 10-15 percent lower specific fuel consumption. However, such improvements could only be achieved by a vigorous component development program. The baseline NASA program will develop improved components which would then be proved out in an experimental engine program. Technology readiness for future engine designs would be demonstrated in the first half of the 1980's. Engines using this technology could be expected to be ready for use on new aircraft introduced into service around 1990. Supplementary component development work which would permit the participation of more than one contractor is defined as part of the Level II program.

Turboprops - Preliminary performance calculations indicate that fuel savings of the order of 20 percent may be associated with the high propulsion efficiency of propellers. Many questions are open with regard to the performance of propeller-driven aircraft at speeds and altitudes approaching those of current jet transports. These questions will be addressed in preliminary phases of a program aimed at demonstration of a reliable turboprop propulsion system. Work through engine demonstration is included in the baseline program. A flight demonstration using a transport aircraft is included in the Level II program.

Fuel Conservative Transport - This activity is directed at the evolutionary improvement of aerodynamic design and the development of active controls technology. NASA will continue to work closely with the manufacturing industry to reoptimize designs based on increased fuel prices and to provide the technological base for such designs. Higher aspect ratio wings with lower sweep and improved airfoil sections will be designed based on improved numerical methods and the results of extensive wind tunnel tests. Critical problems of active controls to permit designs with reduced static stability

margins will be addressed. It appears that savings of the order of 15-20 percent are possible. How much of this can be attributed to a more vigorous NASA program is not clear, but the joint efforts of NASA and industry can produce the technological base for more fuel conservative aerodynamic designs. These technologies will be ready for application to new designs in the early 1980's. It is possible that some aerodynamic changes could be incorporated in the design of derivatives of currently produced aircraft.

Laminar Flow Control - One of the technology elements with the greatest potential for fuel savings is drag reduction by laminar flow control. The concept is to remove the surface boundary layers by suction in order to maintain laminar flow and the low drag associated with such flow. This has been a tantalizing research area for some time. Previous efforts by the Air Force and Northrop on the X-21 research aircraft did demonstrate the possibility of flow laminarization but did not answer the open questions concerning structural concepts, pumping systems, maintainability and reliability. There has been sufficient progress in materials and structures to warrant another attempt to develop a practical system for laminar flow control. A phased program is structured to start in concept development and to proceed into system development and flight test if early results are encouraging. Such a laminar flow control system could only be incorporated into a completely new design aircraft and the technology would not be available before 1985. However, if these efforts are successful, then impressive fuel savings, of the order of 20-40 percent, may be available.

Composite Primary Structures - The use of composite materials in the primary structural components of aircraft offers the potential of substantial vehicle weight savings. These weight savings translate into fuel savings of the order of 10-15 percent as compared with all-metal aircraft. Extensive service experience is required before the airframe industry will commit to the extensive use of composites in new production aircraft. The NASA program is structured to minimize the risks associated with such a commitment by

industry. The previously planned NASA program called for in-service flight evaluation of a composite vertical tail and wing. Additional elements included are (1) expansion of the vertical tail program to include three major airframe manufacturers and an increased number of parts to be fabricated, and (2) construction and service evaluation of a composite fuselage section. The previously planned NASA program (vertical tail and wing) and item (1) are included in the baseline program. Item (2) is added in the Level II program.

Resources

Each of the technology elements discussed above was defined in phases. Funding requirements by fiscal year were estimated for each phase of every element. The total cost over the ten year period (1976-1985) of all elements discussed is \$670 million. If those elements of lower priority which were judged highly promising are not included, the total cost of the baseline program is \$490 million. These costs are based on the assumption that all phases of the technology elements are pursued to completion.

Table I presents a breakdown of funding requirements by fiscal year for the technology elements and their phases.

Benefits

The potential fuel savings associated with the different technology elements are presented along with a description of the technology element. It is difficult to determine precisely how the benefits of these technologies would combine in any one aircraft. Further, in estimating the benefits of this program it is necessary to first identify the gains that would be made by industry's efforts without benefit of the government-sponsored program. NASA is continuing to develop a model of the future air transport fleet and methods to assess the impact of advanced technology. However, it does appear that the efforts of industry combined with the

results of a vigorous government-sponsored research program could result in a reduction of from 40 to 50 percent in the amount of fuel required per unit of passenger travel. Achievement of this goal is dependent on many factors-- successful technological development, market demand for new aircraft, capitalization for development cost of new aircraft, etc.

These factors are well beyond the control of any one group and cannot be predicted with any certainty. The Aircraft Fuel Conservation Technology Task Force Report attempts to identify technology elements with a reasonable hope of successful development which, if implemented, could have a significant favorable impact on fuel consumption.

Advisors

In developing these plans the Task Force has interacted strongly with the aircraft and engine manufacturers as well as major airlines. The plan has been reviewed at least once by each of the following:

- (a) An Advisory Board specially constituted for the purpose of advising NASA on this subject.
- (b) National Research Council Aeronautics and Space Engineering Board.
- (c) Research and Technology Advisory Council.
- (d) Management Council of the Office of Aeronautics and Space Technology.

The plans presented herein reflect the counsel received from these advisors.

SUMMARY OF TASK FORCE RECOMMENDATIONS

R&D \$ IN MILLIONS

Fiscal Year	'76	'76TP	'77	'78	'79	'80	'81	'82	'83	'84	'85	Totals
<u>BASELINE PROGRAM</u>												
<u>Engine Component Improvement</u>	<u>1.5</u>	<u>0.5</u>	<u>9.0</u>	<u>10.0</u>	<u>12.0</u>	<u>7.0</u>	<u>-</u>	<u>-</u>	<u>-</u>	<u>-</u>	<u>-</u>	<u>40.0</u>
<u>Fuel Conservative Engines</u>	<u>1.5</u>	<u>0.5</u>	<u>6.0</u>	<u>12.0</u>	<u>30.0</u>	<u>35.0</u>	<u>20.0</u>	<u>10.0</u>	<u>-</u>	<u>-</u>	<u>-</u>	<u>115.0</u>
I Component Development	1.5	0.5	6.0	7.0								15.0
II Engine Component Development				5.0	30.0	25.0						60.0
III Experimental Engine						10.0	20.0	10.0				40.0
<u>Turboprops</u>	<u>1.4</u>	<u>0.6</u>	<u>3.0</u>	<u>6.0</u>	<u>11.0</u>	<u>20.0</u>	<u>26.0</u>	<u>7.0</u>	<u>-</u>	<u>-</u>	<u>-</u>	<u>75.0</u>
I Prop. Aerodynamics	1.4	0.6	3.0	3.0								8.0
II Prop. Structures - Gears				3.0	6.0	8.0						17.0
III Engine Demonstration					5.0	12.0	26.0	7.0				50.0
<u>Fuel Conservative Transport</u>	<u>1.5</u>	<u>0.5</u>	<u>4.0</u>	<u>8.0</u>	<u>11.0</u>	<u>11.0</u>	<u>10.0</u>	<u>4.0</u>	<u>-</u>	<u>-</u>	<u>-</u>	<u>50.0</u>
I Aerodynamic Development	1.5	0.5	4.0	5.0	4.0							15.0
II Transport Design Validation				2.0	5.0	3.0						10.0
III Technology Flight Demonstration				1.0	2.0	8.0	10.0	4.0				25.0
<u>Laminar Flow Control</u>	<u>0.8</u>	<u>0.2</u>	<u>3.0</u>	<u>6.0</u>	<u>10.0</u>	<u>13.0</u>	<u>16.0</u>	<u>20.0</u>	<u>18.0</u>	<u>10.0</u>	<u>3.0</u>	<u>100.0</u>
I Concept Development	0.8	0.2	3.0	3.0								7.0
II System Development				3.0	10.0	13.0	7.0					33.0
III System Flight Demonstration							9.0	20.0	18.0	10.0	3.0	60.0
<u>Composite Primary Structures</u>	<u>0.5</u>	<u>0.5</u>	<u>16.0</u>	<u>25.0</u>	<u>27.0</u>	<u>23.0</u>	<u>13.0</u>	<u>5.0</u>	<u>-</u>	<u>-</u>	<u>-</u>	<u>110.0</u>
<u>TOTAL BASELINE PROGRAM</u>	<u>7.2</u>	<u>2.8</u>	<u>41.0</u>	<u>67.0</u>	<u>101.0</u>	<u>109.0</u>	<u>85.0</u>	<u>46.0</u>	<u>18.0</u>	<u>10.0</u>	<u>3.0</u>	<u>490.0</u>
<u>LEVEL II PROGRAM</u>												
Fuel Conservative Engine, Additional Component Development	-	-	-	5.0	30.0	25.0	-	-	-	-	-	60.0
Turboprop Flight Test	-	-	-	-	-	-	5.0	20.0	20.0	5.0	-	50.0
Composite Fuselage	-	-	3.0	16.0	19.0	14.0	8.0	7.0	3.0	-	-	70.0
<u>TOTAL LEVEL II PROGRAM</u>	<u>-</u>	<u>-</u>	<u>3.0</u>	<u>21.0</u>	<u>49.0</u>	<u>39.0</u>	<u>13.0</u>	<u>27.0</u>	<u>23.0</u>	<u>5.0</u>	<u>-</u>	<u>180.0</u>
<u>TOTAL PROGRAM</u>	<u>7.2</u>	<u>2.8</u>	<u>44.0</u>	<u>88.0</u>	<u>150.0</u>	<u>148.0</u>	<u>98.0</u>	<u>73.0</u>	<u>41.0</u>	<u>15.0</u>	<u>3.0</u>	<u>670.0</u>

TABLE I

INTRODUCTION

On January 31, 1975, Senator Frank E. Moss, Chairman, and Senator Barry Goldwater, Ranking Minority Member, of the Committee on Aeronautical and Space Sciences asked Dr. James C. Fletcher, NASA Administrator, to establish a challenging but realistic goal and a comprehensive program plan for aeronautical technology development. This technology would make possible a substantial improvement in the efficiency of air transport fuel utilization while minimizing the adverse environmental impact of aircraft operations. The Senators' request asked that NASA's program plan describe the planned technology developments and their costs, major milestones, and fuel savings potentials. The Senators' letter to Dr. Fletcher is attached as Appendix A.

In response to this request, NASA established a Task Force which was constituted on February 24, 1975, and made up of government scientists and engineers from NASA, the Department of Transportation, the Federal Aviation Administration, and the Department of Defense. The Task Force personnel are listed in Table 1.

The Task Force obtained recommendations for potential technology developments from a variety of sources. Inputs were solicited from the NASA research centers, from major engine and airframe manufacturers, and from other government agencies. From these inputs the Task Force formed a preliminary technology plan as a mechanism for review and further input from the NASA research centers, the transport aircraft and aircraft engine manufacturers, and major airlines. A schedule of Task Force activities is shown in Table 2.

In order to interact with the user community to the fullest extent possible, NASA, on April 17, 1975, formed an advisory board made up of representatives from the industry, the airlines, other government agencies, and universities. The membership of the Advisory Board is given in Table 3.

The Advisory Board first met on May 7, 1975, to review and comment on NASA's preliminary program plan. The recommendations of the Board on the preliminary plan are given in Appendix B. Based on these comments and further inputs from the NASA Center Directors, the Task Force revised the preliminary program plan and presented

it to the Advisory Board at a second meeting held on June 18, 1975. The Board's comments and recommendations to the revised plan are given in Appendix C. In addition, the revised plan was presented to the Aeronautics and Space Engineering Board of the National Research Council and to the NASA Research and Technology Advisory Council.

The Task Force developed the final technical program plan, which is the body of this report, reflecting counsel received from all of these advisors. This plan was presented to the Advisory Board at the third and final meeting on September 4, 1975. NASA is currently evaluating the Task Force recommendations to determine how and to what extent the initial phases of the program will be supported. Subsequent fiscal year funding will be determined in the budget development process and will be subject to an overall assessment of budget priorities.

Before addressing the technical plan, a background of the fuel shortage as it pertains to the airline industry is presented. The proposed NASA Aircraft Fuel Conservation Technology Program is then described, including technical content, development schedules and resource requirements. In the final section, an estimate is made of the potential fuel savings associated with the implementation of the different technologies.

AIRCRAFT FUEL CONSERVATION TECHNOLOGY TASK FORCE

OAST	—	JIM KRAMER (DIRECTOR) JOHN KLINEBERG BILL MCGOWAN FRED POVINELLI BILL ROUDEBUSH
AMES	—	DARRELL WILCOX LOU WILLIAMS
FLIGHT	—	HERM REDIESS
LANGLEY	—	DEL NAGEL JOE ALFORD DAL MADDALON
LEWIS	—	MILT BEHEIM DICK WEBER
DOD	—	DICK BAIRD
DOT	—	BILL DEVEREAUX
FAA	—	JOE TYMCZYSZYN

TABLE 1

CHRONOLOGY OF TASK FORCE ACTIVITIES

FEBRUARY 24	TASK FORCE ESTABLISHED
FEBRUARY 24 - 25	BRIEFINGS BY NASA CENTER REPRESENTATIVES
26 - 28	BRIEFINGS BY:
	BOEING GENERAL ELECTRIC
	DOUGLAS PRATT & WHITNEY
	LOCKHEED HAMILTON STANDARD
MARCH 17 - 31	DEVELOPMENT OF PRELIMINARY TECHNICAL PLAN
MARCH 24	REVIEW PRELIMINARY TECHNICAL PLAN WITH OAST MANAGEMENT COUNCIL (CENTER DIRECTORS)
MARCH 31 - APRIL 14	REVIEW PRELIMINARY PLAN WITH MANUFACTURERS AND AIRLINES
	BOEING ALLISON UNITED
	LOCKHEED (CA) GENERAL ELECTRIC DELTA
	DOUGLAS PRATT & WHITNEY EASTERN
	LOCKHEED (GA) HAMILTON STANDARD TWA
APRIL 17	ESTABLISH ADVISORY BOARD
MAY 7	BRIEFING TO ADVISORY BOARD
MAY 20	BRIEFING TO OAST MANAGEMENT COUNCIL (CENTER DIRECTORS)
JUNE 18	SECOND MEETING OF ADVISORY BOARD
JUNE 24	BRIEFING TO AERONAUTICS AND SPACE ENGINEERING BOARD
JULY 22	BRIEFING TO RESEARCH AND TECHNOLOGY ADVISORY COUNCIL
AUGUST 1	SUBMIT EXECUTIVE SUMMARY OF TASK FORCE REPORT TO SENATE AERONAUTICAL AND SPACE SCIENCES COMMITTEE
SEPTEMBER 4	THIRD MEETING OF ADVISORY BOARD

TABLE 2

MEMBERSHIP

ADVISORY BOARD ON AIRCRAFT FUEL CONSERVATION TECHNOLOGY

DR. RAYMOND L. BISPLINGHOFF (CHAIRMAN) – UNIV. OF MISSOURI
PROF. JACK L. KERREBROCK – MASSACHUSETTS INSTITUTE OF TECH.
MR. FRANKLIN W. KOLK – AMERICAN AIRLINES, INC.
MR. JOHN G. BORGER – PAN AMERICAN WORLD AIRWAYS
DR. RONALD SMELT – LOCKHEED AIRCRAFT CORPORATION
MR. CHARLES S. GLASGOW, JR. – DOUGLAS AIRCRAFT COMPANY
DR. ABE SILVERSTEIN – REPUBLIC STEEL CORPORATION
DR. MICHAEL I. YARYMOVYCH – ENERGY RESEARCH & DEVELOPMENT ADMIN.
MR. WILLIAM E. STONEY – DEPARTMENT OF TRANSPORTATION
MR. JAMES F. RUDOLPH – FEDERAL AVIATION ADMINISTRATION
MR. ROBERT N. PARKER – DEPARTMENT OF DEFENSE/DDR&E
MR. RICHARD COAR – PRATT AND WHITNEY AIRCRAFT DIVISION
MR. H.W. WITHINGTON – BOEING COMMERCIAL AIRPLANE COMPANY
MR. EDWARD WOLL – GENERAL ELECTRIC COMPANY

TABLE 3

FUEL CRISIS BACKGROUND

During the past 25 years, U.S. energy consumption has more than doubled. Figure 1 shows that the total energy consumption in the U.S. has increased from 34×10^{15} BTU in 1950 to approximately 78×10^{15} BTU in 1974. Transportation has consistently accounted for about 25% of all energy consumption. The energy consumed for transportation in 1974 was approximately 18×10^{15} BTU. The distribution of this energy for different modes of transportation is shown in Figure 2. Transportation is highly dependent on fuels derived from petroleum. While only 45% of the energy demand for all uses is supplied by petroleum, 95% of the transportation energy is from petroleum. Of course, all aviation energy requirements are supplied by petroleum fuels.

The growth in aviation energy consumption is shown in Figure 3. As shown in this figure, the energy consumption for commercial aviation has tripled in the past ten years. This growth in commercial aviation has been brought about largely through the introduction of jet aircraft in the late 1950's which greatly improved the comfort, speed, cost, and reliability of air transportation.

Forecasts of the future fuel consumption requirements for air transportation are shown in Figure 4. Although the growth in revenue passenger miles during the 1960's has been very great, most estimates, including those made before the energy crisis, forecast some reduction in growth rate. However, even conservative projections indicate more than a doubling of the fuel required for air transportation by the year 2000.

In November 1973, previous concerns about a dwindling petroleum supply were emphasized by the OPEC oil embargo and the resulting energy crisis. This crisis resulted in fuel allocations and major step increases in fuel prices. While the fuel allocations have disappeared, the fuel price has remained fairly stable at high levels. However, several possible actions by foreign oil producers or the U.S. government could result in price increases in the near future. Economic dislocations caused by the high fuel prices persist and constitute a serious problem for the air transport industry.

Until the end of 1973, the price that the airlines paid for jet fuel had remained relatively constant for many years. In the past year and one-half, as shown in Figure 5, domestic fuel prices have doubled and international fuel prices have tripled.

The airlines responded to fuel allocations by reducing schedule frequency, grounding some aircraft, and instituting fuel-conservative operational procedures. It has been estimated that this response resulted in about a 10% fuel savings compared to pre-crisis use. Maximum use of fuel conservative operational procedures alone (carrying less extra fuel, flying at optimum altitudes, and flying at slower speeds) could have accounted for nearly one-third of the savings. The aircraft manufacturing industry assisted by determining fuel-conservative operational procedures to reduce fuel usage. The FAA worked with the airlines by implementing energy efficiency programs and responsive air traffic control (ATC) procedures emphasizing fuel-efficient aircraft operation.

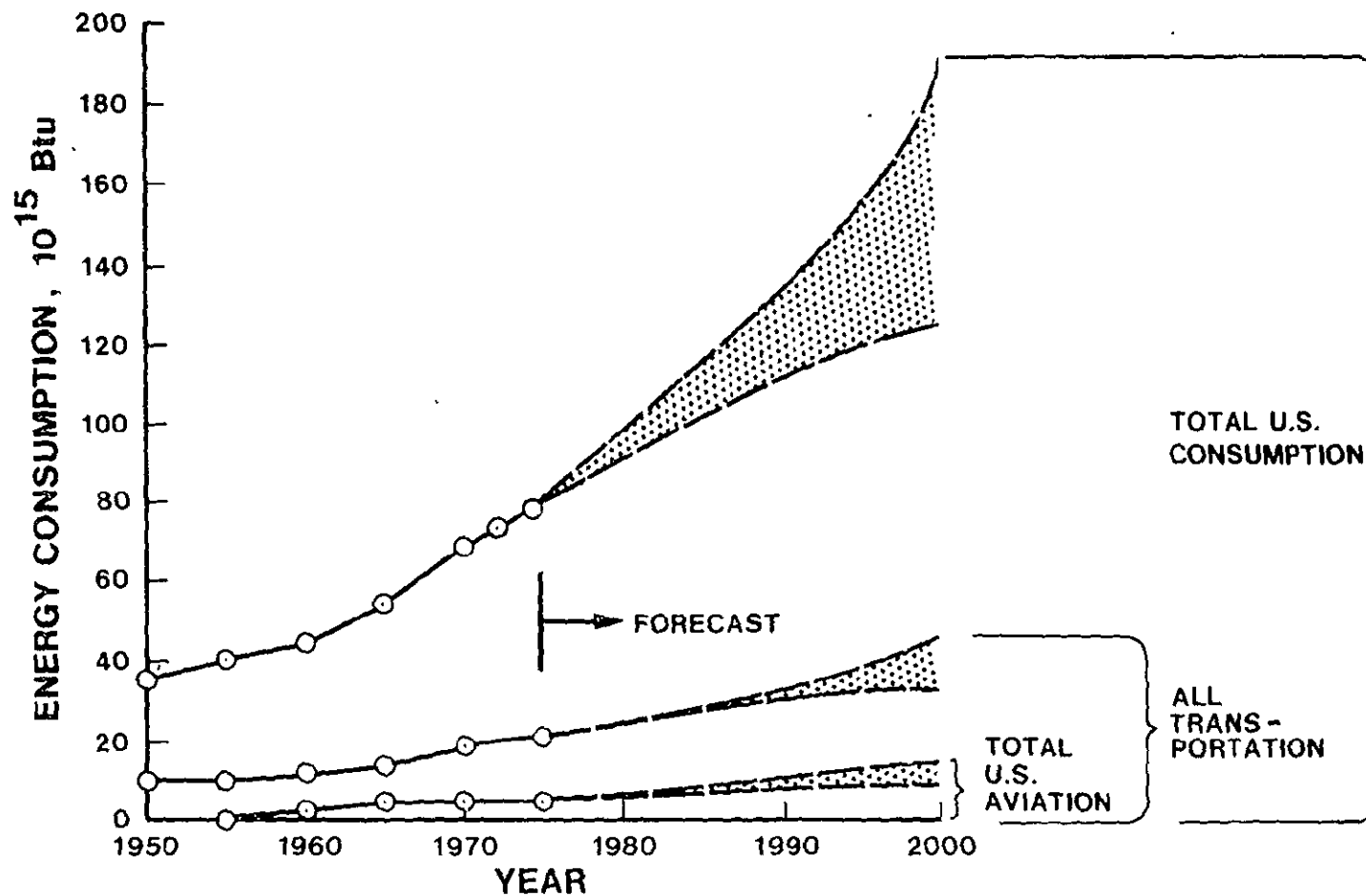
Fuel allocations impact the airlines somewhat differently and potentially more seriously than fuel price increases. With the ending of fuel allocations, some of the initial reaction to the energy crisis has been moderated. Flight frequencies are being restored and some grounded aircraft are flying again. The emphasis has now shifted to the research and development necessary for substantial increases in operational efficiency and more efficient future aircraft. In order to understand the potential for future improvements in aircraft efficiency, it is important to understand the current fleet and its fuel usage.

The fuel efficiency of various aircraft versus average stage length is shown in Figure 6. Aircraft energy efficiency is shown in terms of gal/seat n. mi. plotted against the average stage length of that aircraft for each airline operator. A natural grouping of the data indicates the increasing aircraft efficiency with longer stage length, with larger aircraft, and with the newer widebody aircraft. It is important to note, however, that while larger aircraft are more fuel efficient than smaller aircraft at equal load factor, aircraft size must be carefully matched to passenger demand. A larger aircraft carrying the same number of passengers as a smaller aircraft will be less efficient. A determination of the most fuel-efficient aircraft requires a detailed analysis of the particular route, aircraft efficiency, and passenger demand.

Figure 7 shows the distribution of aircraft fuel usage for the U.S. scheduled carriers operating on the domestic routes. The dominant fuel usage on the shorter trip length for these domestic routes is evident. The fuel consumption by propeller aircraft is insignificant compared to jet aircraft. This distribution of fuel usage is shown again in a different form in Figure 8. Domestically, 34% of the airline fuel consumption is for trips of less than 500 statute miles and 59% is for trips of less than 1000 st. miles. The largest single fuel consumer by aircraft type is the Boeing 727, which consumes 38% of the domestic airline fuel. This fuel consumption for the Boeing 727 reflects the large number of aircraft of this type in service.

The number of each aircraft type in the U. S. jet transport fleet is shown in Table 4. This fleet, which includes 2204 jet aircraft, represents almost one-half of the total world jet fleet of 4770 aircraft. Because most of this existing transport fleet is made up of relatively recently-produced aircraft, any aviation fuel conservation program must include consideration of improvements to existing aircraft as well as the development of new fuel-conserving aircraft.

U.S. ENERGY CONSUMPTION 1950-2000



IN 1972 U.S. TOTAL ENERGY USE WAS 31% OF TOTAL WORLD ENERGY USE

FIGURE 1

U.S. TRANSPORTATION ENERGY CONSUMPTION

1960-1973

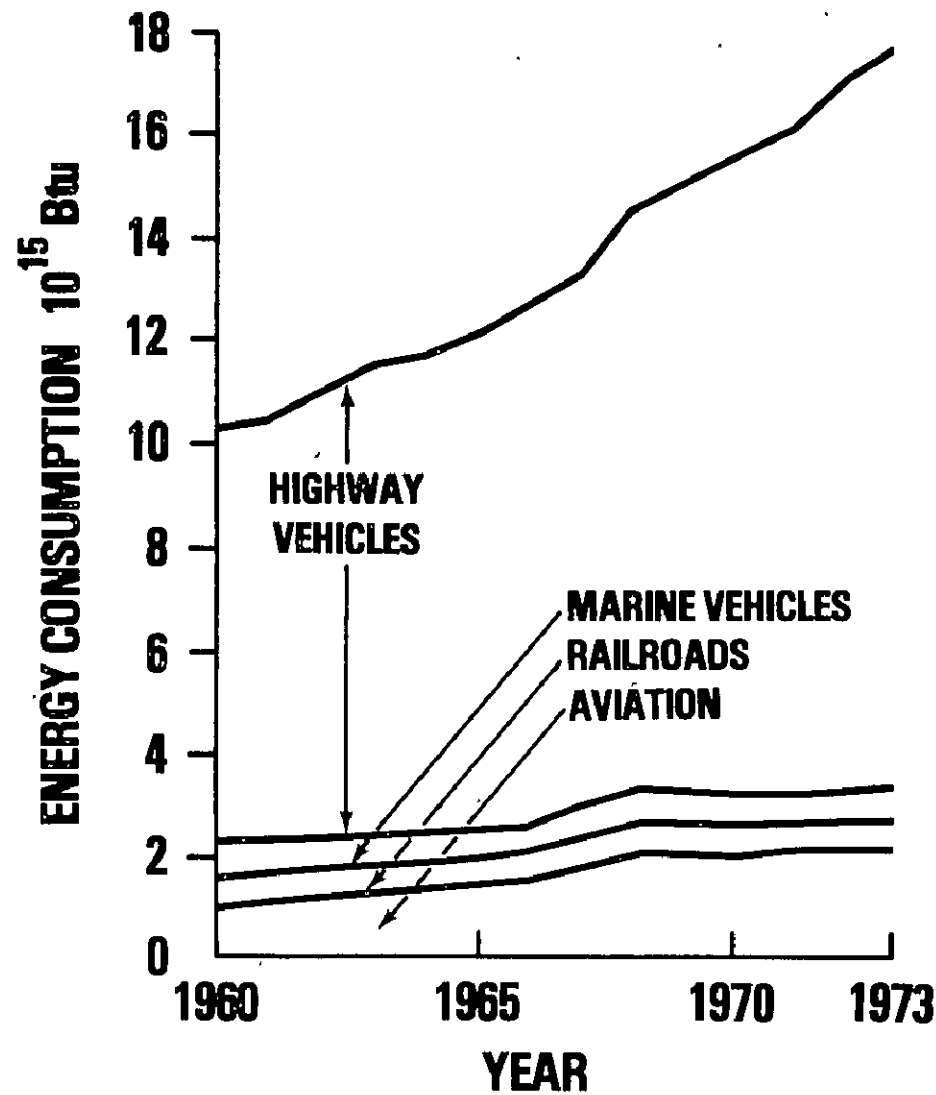


FIGURE 2

U.S. AVIATION FUEL CONSUMPTION

1955-1973

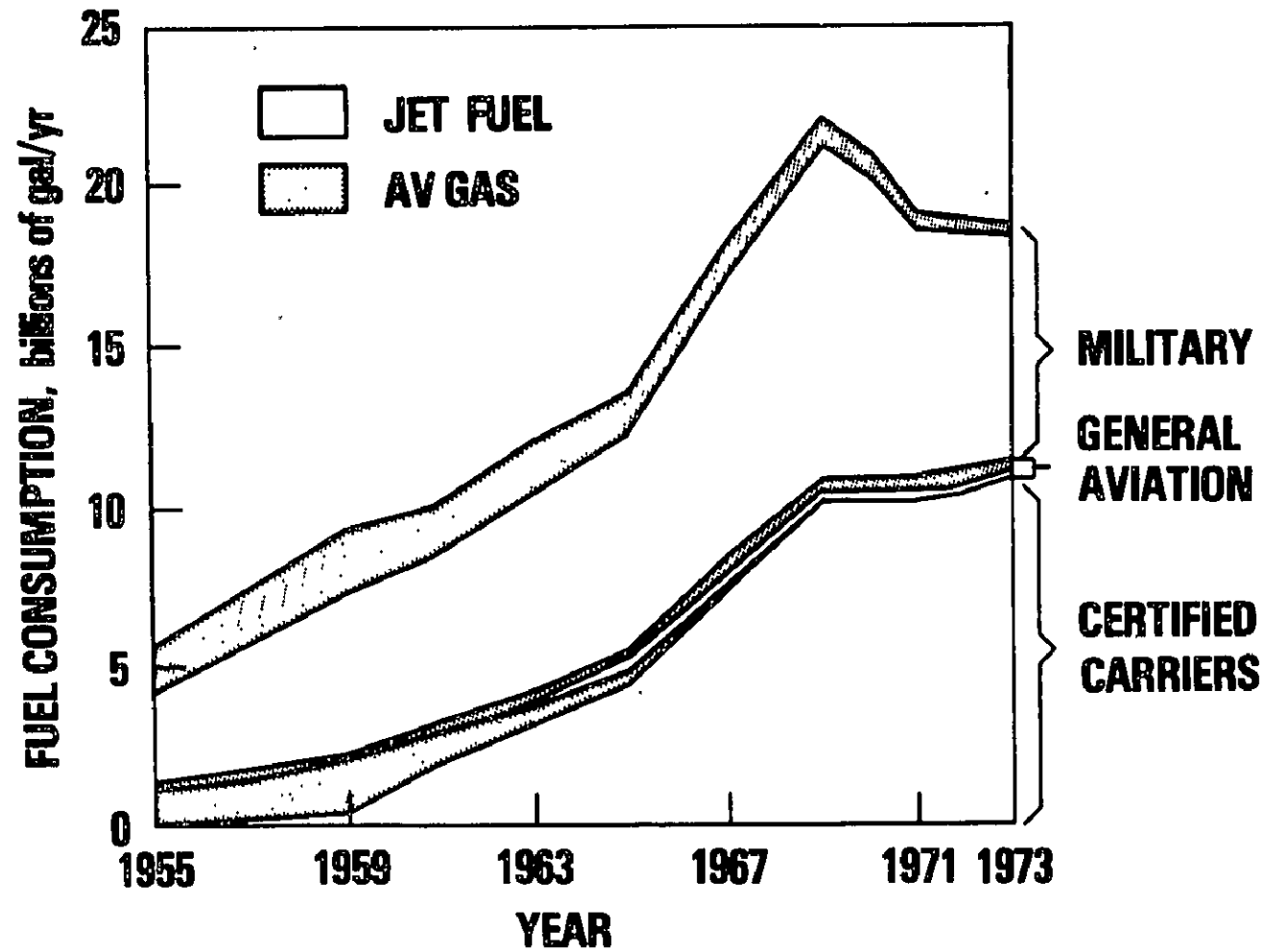


FIGURE 3

U.S. AIR TRANSPORTATION FUEL CONSUMPTION CERTIFICATED AIRLINES

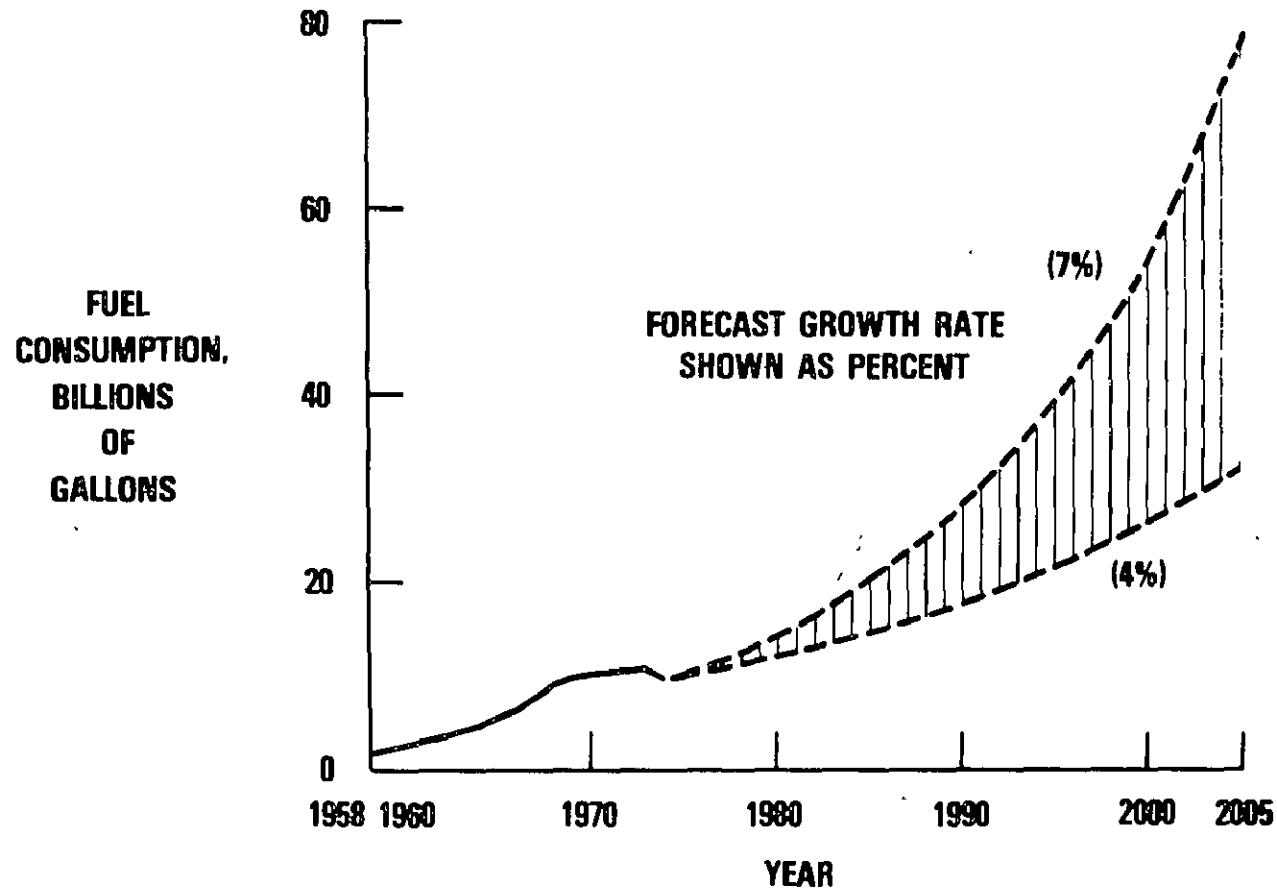


FIGURE 4

AVERAGE U.S. COMMERCIAL JET FUEL PRICE

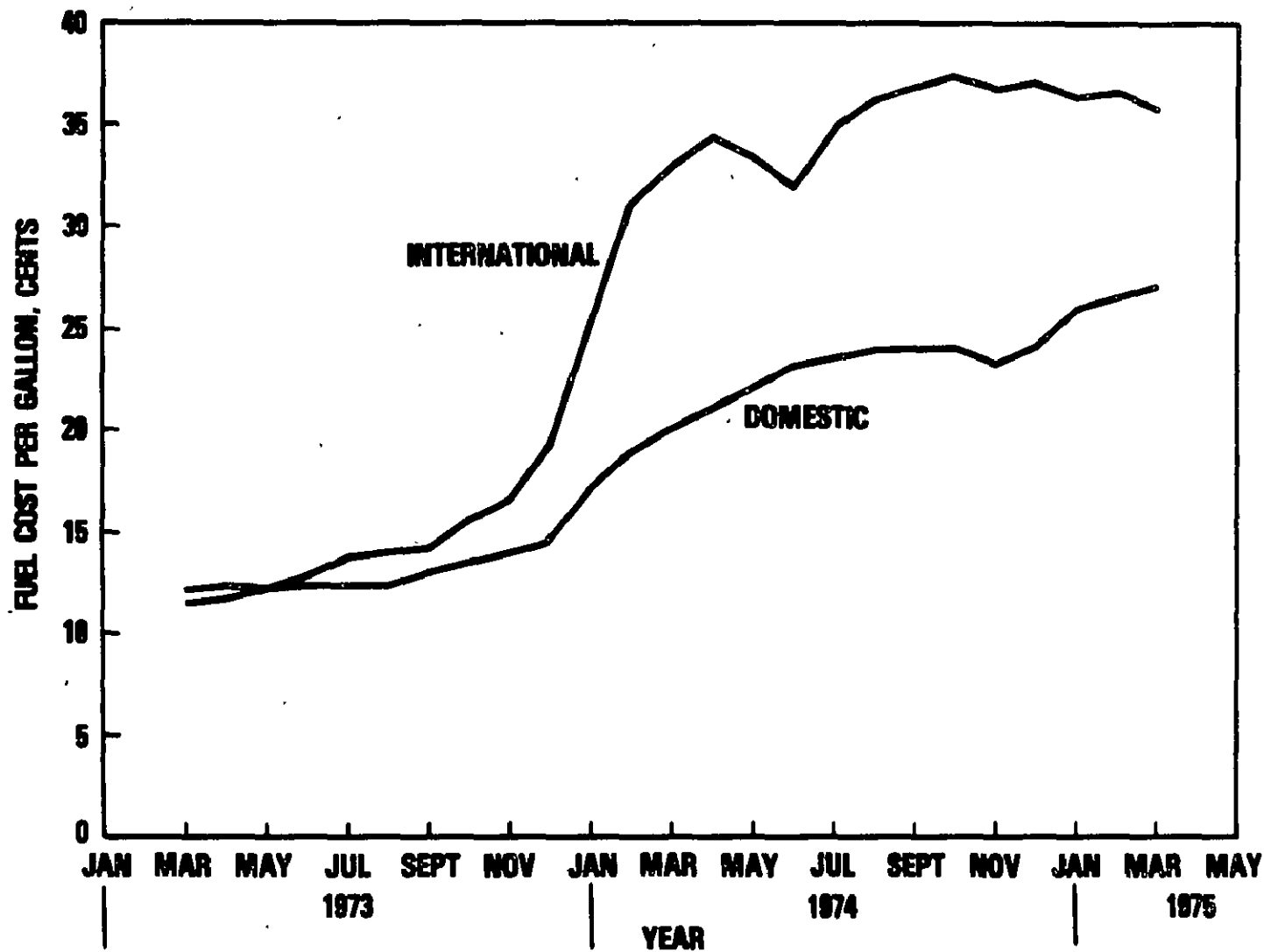


FIGURE 5

AIRLINE AIRCRAFT FUEL CONSUMPTION

1972 CAB EQUIPMENT TYPE BY INDIVIDUAL CARRIER

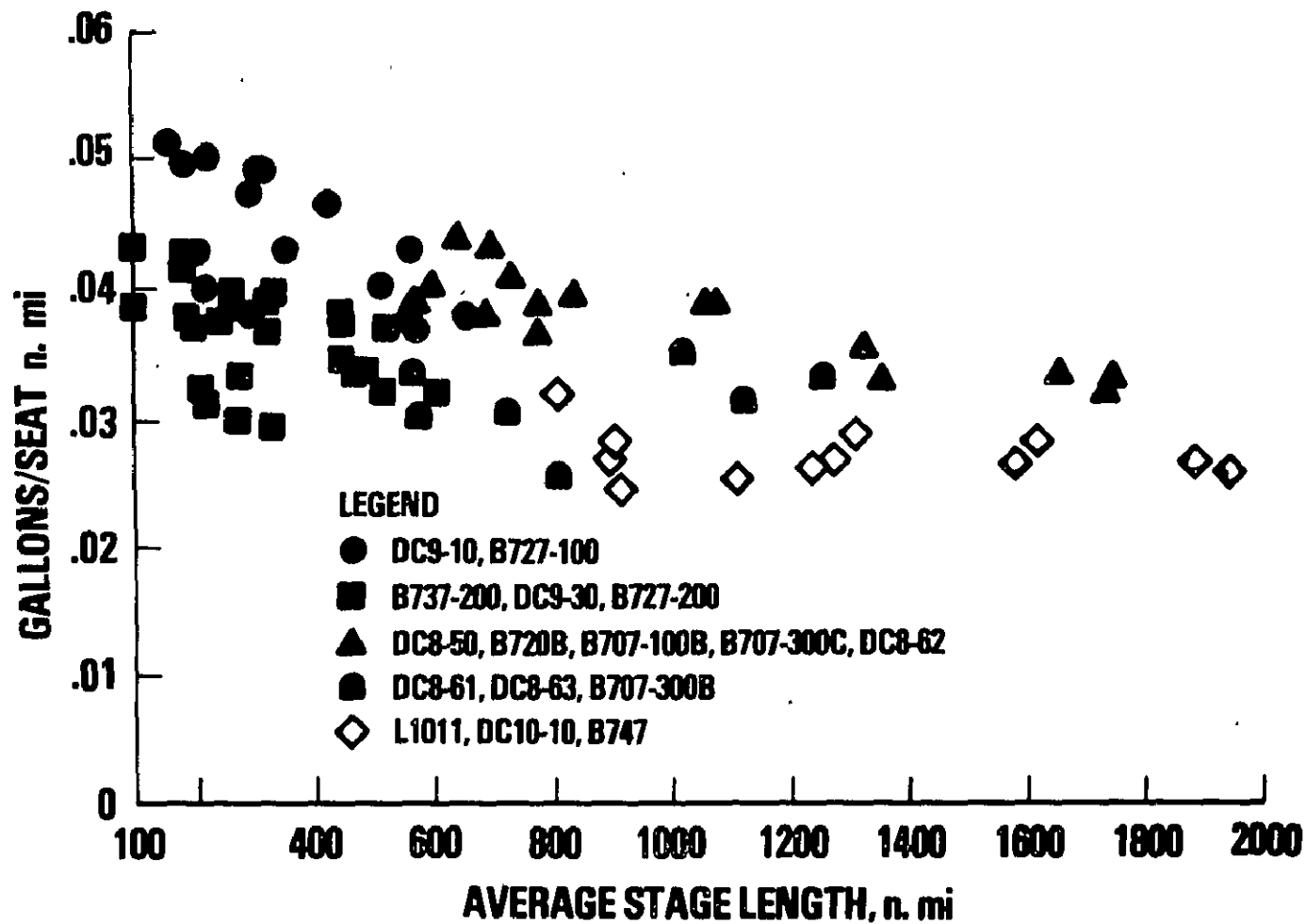


FIGURE 6

AIRCRAFT FUEL USAGE

SCHEDULED DOMESTIC CARRIERS

AVERAGE FOR AUGUST 1974

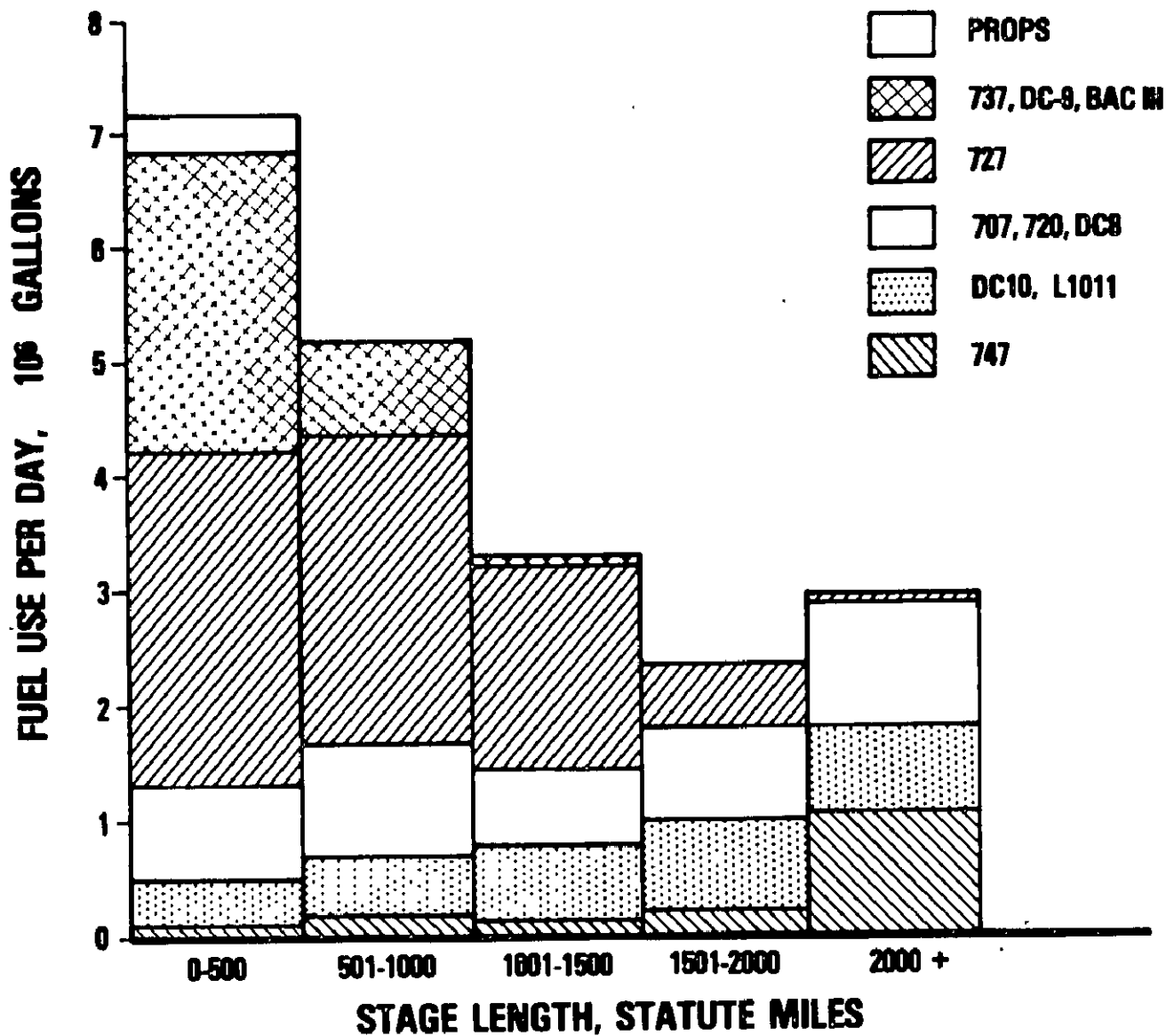


FIGURE 7

AIRCRAFT FUEL USE DISTRIBUTION

SCHEDULED CARRIERS, DOMESTIC OPERATIONS
AVERAGE FOR AUGUST 1974

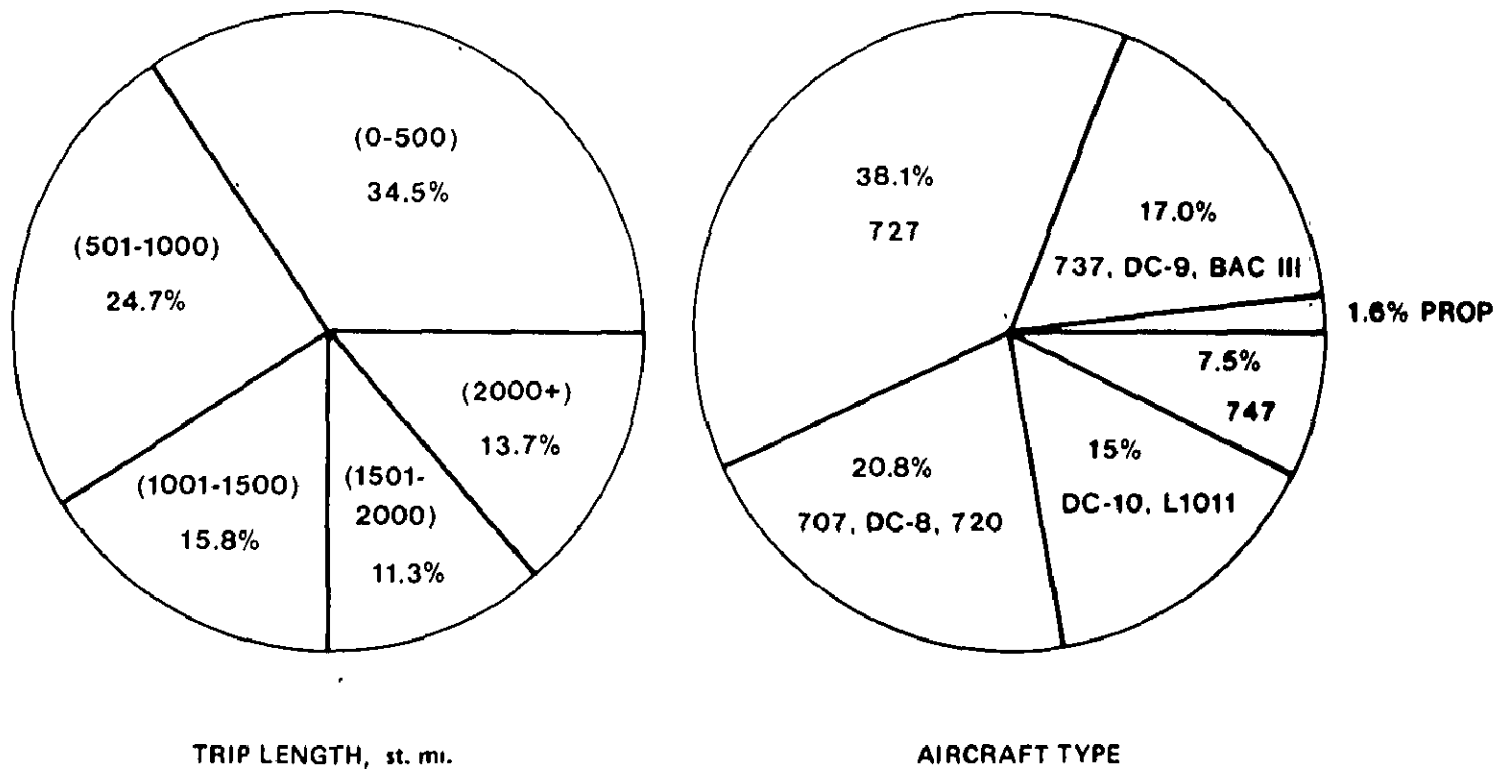


FIGURE 8

JET TRANSPORT FLEET

ON-HAND JANUARY 1, 1975

AIRCRAFT TYPE

U.S. AIRLINES

WORLD AIRLINES (INC. U.S. & NON-AIRLINE, EXCL USSR AIRCRAFT)

B-737

153

368

DC-9

334

706

BAC-111

48

209

B-727

753

1066

B-720 & 707

369

822

DC-8

223

519

C-880 & 990

38

80

L-1011

65

86

DC-10

110

168

B-747

111

242

OTHER

0

504

TOTAL

2204

4770

TABLE 4

TECHNOLOGY PLAN

The Task Force reviewed possible advances in all areas of aeronautical technology and solicited inputs from all sectors of the aviation community. Six major programs were then defined that could result in conservation of fuel use in air transport. Of these six, three are evolutionary improvements in propulsion and aerodynamics. The remaining three, turboprops, laminar flow control and composite primary aircraft structures, represent attempts to develop technology that is considerably different from that in current use in civil air transports.

A firm ground rule in the development of the plan was that none of the technology elements would result in fuel savings at the expense of degrading the environment. Non-technical questions such as regulatory changes which could lead to reduced fuel requirements for the current air transport fleet were not addressed. NASA's traditional role in support of research and technology was assumed to continue and the development of prototype aircraft or engines was not considered in the plan. For certain technology elements, the demonstration of technology readiness requires experimental engine ground tests or proof-of-concept flight tests. The subsequent design, development, certification and production phases were considered to be the responsibility of the airframe and aircraft engine manufacturers.

For each of the six programs, technological development schedules were defined and resource requirements estimated. Each of the technology programs was defined in phases. The fuel savings potential, prospects for implementation in the civil air transport fleet, and the impact of this technology on air transport fuel use were estimated. In several cases two levels of activity are defined for a technology element. Those activities judged to be of first priority were grouped in what is termed the baseline program. Additional work judged to be important but of lower priority was defined and is referred to as Level II. These additional elements are identified in the discussion of the various technology elements. The six programs are grouped as follows and are described in the following sections:

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

Propulsion

- o Engine Component Improvement
- o Fuel Conservative Engine
- o Turboprop

Aerodynamics

- o Fuel Conservative Transport
- o Laminar Flow Control

Structures

- o Composite Primary Aircraft Structures

PROPULSION

Propulsion advances can be classed as those which apply to existing engines in the fleet, to new production of current engine types, and to new engine designs. The Task Force considered technology developments which would apply to all these areas of application as indicated in Figure 9. The projected trends of fuel consumption by various engine types are shown in Figure 10. Currently, low-bypass ratio engines in use on narrow-body transports consume about 75 percent of the fuel used by U.S. scheduled air-carriers. The trend of fuel usage is such that beyond 1985, high-bypass engines will account for most of the fuel consumption of the civil fleet. Lower thrust, high-bypass engines are projected to enter service sometime beyond 1980 on new aircraft.

The first two activities shown in Figure 9 (Improved Engine Maintenance and Ten-ton Engines) were considered extensively by the Task Force but were not included as a part of the program described herein. The first of these which would apply to existing engines, is fuel-savings that might be achieved with changes in airline maintenance procedures. It is well known that aircraft engines in service do not perform as well as they do when they are installed initially. This is illustrated schematically in Figure 11, which shows the changes in engine specific fuel consumption (SFC) with time. The general behavior is for an engine's SFC to increase until the engine is removed from the aircraft for maintenance. At that time performance is improved as worn parts are replaced, clearances adjusted, etc. The result is a drop in SFC. The engine is restored to service and then undergoes further performance deterioration with time. This cyclic maintenance and service gives rise to the saw-tooth character of the curve. In addition to the deterioration which is rectified at the time of maintenance, there is some deterioration which is not restored by current maintenance procedures. That part of the performance deterioration is a cumulative effect that gives rise to the upward trend of the performance deterioration over the life of the engine. It is believed that a better understanding of engine

component deterioration and revised maintenance procedures to incorporate more fuel-efficient components could result in fuel savings of 3 percent in low-bypass engines and from 1 to 3 percent or more in high-bypass engines. The entire transport fleet would be affected. The underlying issue is one of balance between maintenance costs and fuel costs. A further consideration is that maintenance costs are domestic expenditures while fuel costs are partly an import expenditure.

The reaction of the airline industry to a NASA program aimed at revised maintenance procedures was generally unfavorable. There were opinions expressed that the airline maintenance procedures are already very good, fuel costs relative to labor costs are not going to change maintenance procedures at current fuel prices, and SFC is very much secondary to reliability in determining maintenance procedures. Based on this advice there is no work aimed directly at improved maintenance procedures included in this plan. However, a program to understand better the sources of performance degradation of in-service engines was strongly endorsed by the advisors. The primary motivation for such a program is to learn how to forestall performance deterioration in new engines. There is, of course, the possibility that something might be learned which could affect maintenance procedures. Therefore, for this and other reasons the test program would be closely coordinated with airline operators.

The second technology element shown in Figure 12 is concerned with the use of high-bypass engines in the 20,000 to 25,000 lb. thrust class or "ten-ton" engines. These engines, namely the CFM56 and the JT10D, are in development and are based on the same technology used in the high-bypass-ratio engine delivering 40,000-50,000 pounds of thrust and used on the wide-body aircraft. This technology is clearly well-established and no significant advance is required to apply it to the lower thrust (ten-ton) engines. The high-bypass-ratio cycle results in SFC reductions of the order of 15 - 20% relative to the low-bypass-ratio engines currently used on the narrow-body fleet. These fuel savings are not sufficient, however, to motivate airlines to retrofit high-bypass-ratio engines onto their existing narrow-body fleet. Furthermore, the use of these engines in new production of derivative aircraft appears doubtful because of their relatively high initial cost. Thus, a significant fuel savings technology is available that will not soon be used because of the lack of economic motivation. The Advisory Board pointed out most emphatically that simple profit motivation drives U.S. manufacturers and operators to equipment requiring larger expenditures for imported

oil rather than to equipment that would require a significant development investment in U.S. industry with smaller expenditures for foreign oil.

The propulsion activities recommended by the Task Force are 1) Engine Component Improvement, 2) Fuel Conservative Engine, and 3) Turboprop. Under Engine Component Improvement are a group of component development activities that could be ready in about 1980 and which could be incorporated into future production models of currently available engine designs. Thus the idea is to incorporate fuel-conservative components into engines that will be produced in the early 1980's.

The second activity, Fuel Conservative Engine, is aimed at laying the technology base for a new generation of aircraft engines which would have fuel conservation as a primary design objective. This technology base would consist of the results of an intensive advanced component effort that would lead to demonstration of this advanced technology in an experimental engine.

The technology demonstration activity on turboprops is motivated by the large improvement in SFC that may be available if propellers can be designed with efficiencies above 80% at cruise speeds of the order of Mach 0.8. The SFC improvements would not be usable if aircraft productivity were compromised by substantially lower cruise speeds or an unacceptable level of passenger discomfort caused by high levels of cabin vibration or noise. It is well known that turboprops lost the transport aircraft propulsion system market to the jet engine in the late 1950's. However, since that time significant advances in airfoil and structures technology have been achieved. These advances in conjunction with the increased fuel prices could result in turboprops being an attractive propulsion system.

Each of the propulsion programs will be discussed in a standard format describing the concept, the fuel savings potential, an assessment of the implementation prospects, and program in terms of content, resource requirements, and applications of the technology. The various advisors' comments received which have impacted the formation of the program plan are also presented.

PROPULSION

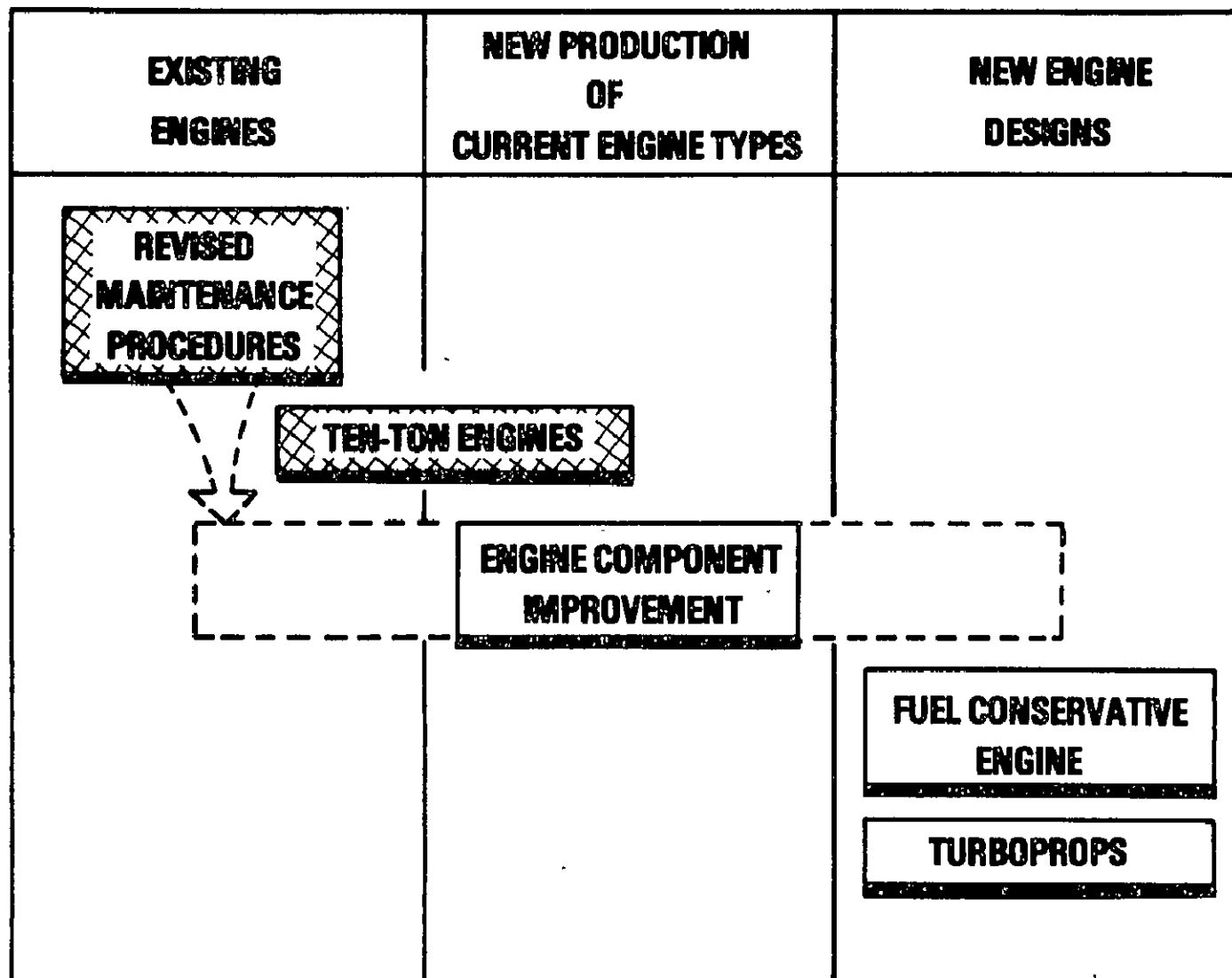


FIGURE 9

FORECAST U.S. SCHEDULED AIRLINES

FUEL USAGE

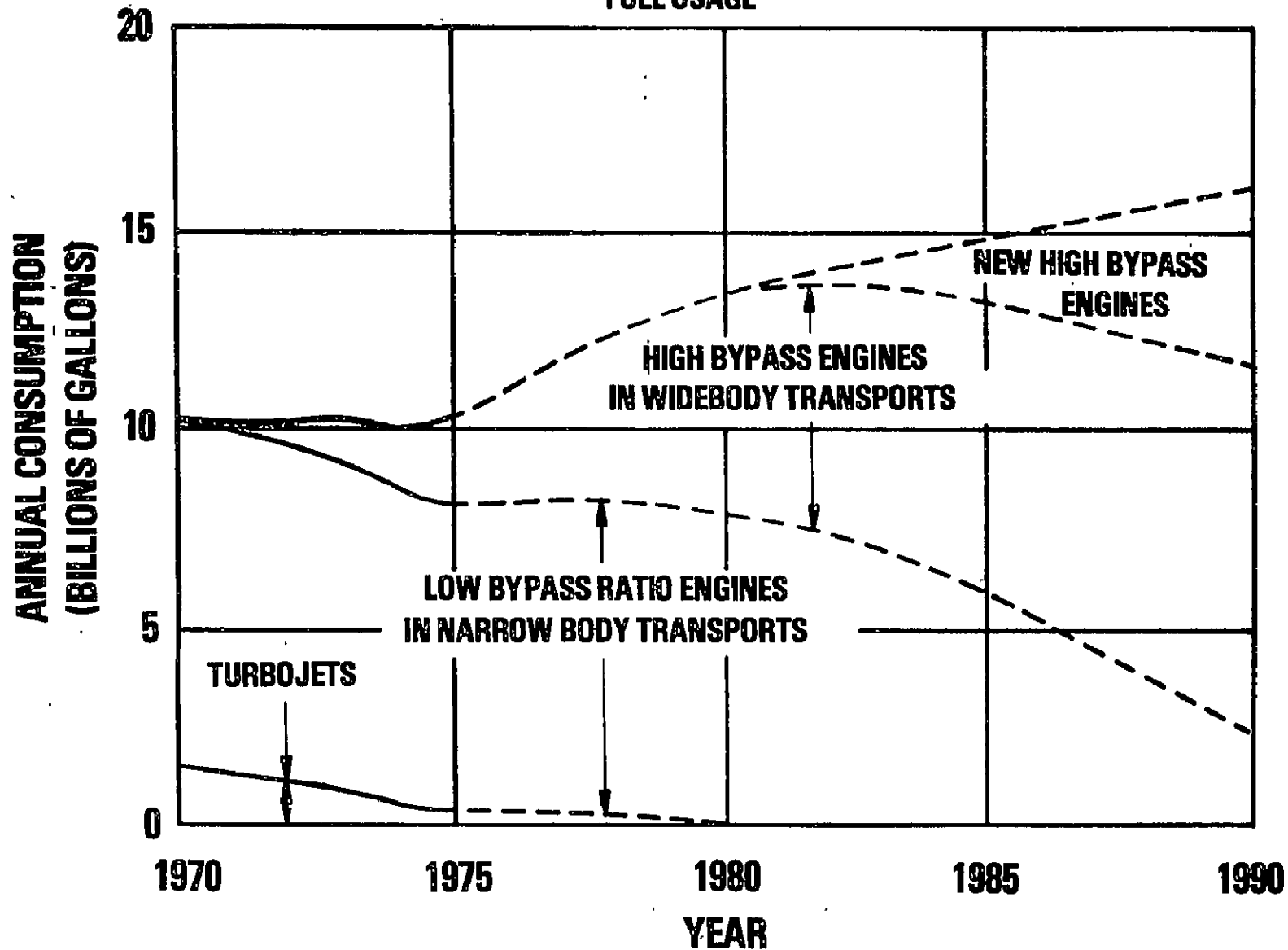


FIGURE 10

PERFORMANCE RETENTION

TSFC PERFORMANCE DETERIORATION TRENDS TYPICAL ENGINE

CURRENT STATUS — 3 TO 8% INCREASE IN AVERAGE REPAIRED ENGINE

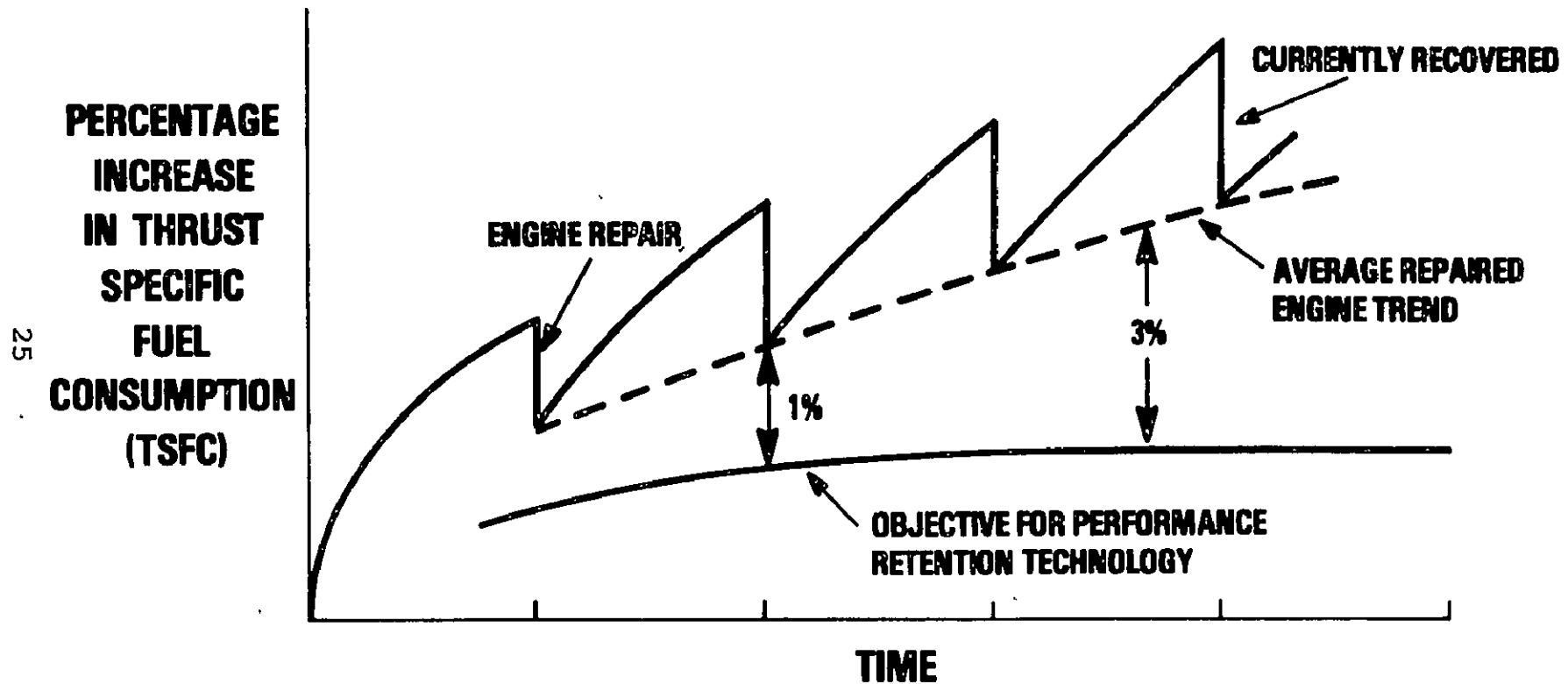


FIGURE 11

INTRODUCE MORE HIGH BYPASS TURBOFANS

STATUS

- **20,000-25,000 LB. THRUST HIGH BYPASS ENGINES ARE BEING DEVELOPED AND COULD BE INTRODUCED INTO THE FLEET BY 1980 OR EARLIER.**
- **THESE ENGINES WOULD PROVIDE 15% FUEL SAVINGS OVER THE ENGINES NOW IN USE IN NARROW-BODY AIRCRAFT.**
- **ECONOMIC FACTORS DO NOT PRESENTLY APPEAR TO FAVOR THE INTRODUCTION OF NEW AIRCRAFT WHICH WOULD REQUIRE THE NEW ENGINES. DERIVATIVE AIRCRAFT MAY NOT USE THEM.**

PROGRAM

- **TECHNOLOGY ROLE FOR NASA NOT CLEAR**

FIGURE 12

Engine Component Improvement

CONCEPT

- o Develop improved performance components for new production of current engines.
- o Conduct diagnostic testing of in-service engines to identify sources of performance degradation. See Figure 13.

A small number of engine types power practically all of the present fleet of commercial airplanes. These engines or variants thereof will continue to be produced for many years to come and will remain in service well beyond 1990. Although the ability to reduce the fuel consumption of these engines is limited, the large number of these engines that will be produced in the future provides the potential for saving large amounts of fuel in the aggregate, if improvements can be incorporated into each newly-produced engine.

FUEL SAVINGS

- o 5% improvement over current engines.

It will require careful analysis by the engine manufacturers to determine what modifications can be effectively and economically achieved for each of the various engine types. The preliminary estimate of average fuel savings of 5% would pertain throughout the lifetime of all narrow- and widebody commercial transports built after approximately 1980, until entirely new engines are introduced at some later date. Some of the improvements may be available for incorporation prior to 1980.

IMPLEMENTATION

Improvements in technology may be incorporated into future production of current engines if economically desirable. The resulting new models may differ in mechanical details, installation factors, thrust level, etc. The motivation for NASA participation in this process is to stress changes especially relevant to fuel conservation, to show that the changes are practical without penalties in safety, reliability, or economy, and to accelerate their implementation. By 1980, the program will have accomplished a series of component tests providing performance data

adequate for engine design use. Where appropriate, the modifications will be demonstrated in engine ground tests.

PROGRAM

The program will develop and demonstrate technology to improve the JT3D, JT8D, JT9D, and CF6. Discussions with the engine manufacturers have identified several examples of the types of component improvements which can be pursued with high promise of increasing the fuel efficiency of current engine types. Identification of additional component improvements will be made as this program is implemented. The four following areas of component improvement appear especially appropriate for NASA-sponsored efforts:

(1) Mixers - Mechanical devices to mix the core and duct streams prior to discharge through a common nozzle can improve the propulsive efficiency and therefore the propulsion system specific fuel consumption. A considerable amount of model data is available, although more may be needed for systematic design purposes. Beyond this there is a need for investigations with full-scale engines with realistic nacelles and nozzles to generate confidence in the predictions. Flight testing may be necessary to assure that there are no adverse nacelle-airframe interactions.

(2) Clearance Control - Leakage around the tips of rotor blades can significantly penalize compressor and turbine efficiency; however, design clearances must be large enough to avoid catastrophic rubbing during off-design and transient conditions. Better techniques for controlling clearances such as active thermal control or improved abradable materials will be investigated.

(3) Seals - The benefits of compliant seals, which adjust to changes in clearances resulting from varying operational conditions, will be investigated for clearance control in appropriate parts of the engine.

(4) Blade Shapes - Current engines suffer substantial deterioration after entering service, probably as a result of erosion and other impact-caused changes to the shape of the fan and compressor airfoils. A research program will develop blade shapes that will decrease

the performance sensitivity to such changes. The associated material and structural considerations will be an integral part of the study.

These areas of component technology improvement will be added to the on-going NASA effort. The on-going effort to improve current engine types is aimed at providing technology to meet the EPA emission standards for 1979 and beyond. At the same time some reduction in fuel use is expected to result.

In addition to component development of the type mentioned above, diagnostic tests of in-service engines will be performed in an attempt to determine the causes of engine performance degradation with time. A sample of in-service engines will be systematically tested to isolate and quantify the component contributions to performance deterioration.

The elements of this Engine Component Improvement Program are illustrated conceptually in Figure 14 with a schedule of activity given in Figure 15. The resource requirements for the additional effort are given by fiscal year in Figure 16. The program increase is estimated to be \$40 million over the next five years. The potential component improvements will be evaluated through component and engine tests.

The improved components are expected to be ready for use on engines produced in the early 1980's. The improvements would be applied to all newly produced engines of current types: JT8D, JT9D, and CF6. The technology will also apply to new engines developed beyond this time period. If economical, some of the improvements could be applied to engines already in the fleet but this would require detailed economic evaluations which would trade labor and parts costs against improved fuel usage.

COMMENTS

The program as structured was supported by all of the advisors with no major disagreement. A list of comments is given in Figure 17.

ENGINE COMPONENT IMPROVEMENT

CONCEPT

- DEVELOP FUEL-EFFICIENT COMPONENTS SUITABLE FOR INCORPORATION IN FUTURE PRODUCTION OF CURRENT ENGINE TYPES.
- CONDUCT DIAGNOSTIC TESTING OF IN-SERVICE ENGINES TO IDENTIFY SOURCES OF PERFORMANCE DEGRADATION.

FUEL SAVINGS

UP TO 5%

BASIS FOR TECHNOLOGY READINESS

COMPONENT AND ENGINE TESTS PROVIDING PERFORMANCE DATA FOR DESIGN USE.

FIGURE 13

ENGINE COMPONENT IMPROVEMENT

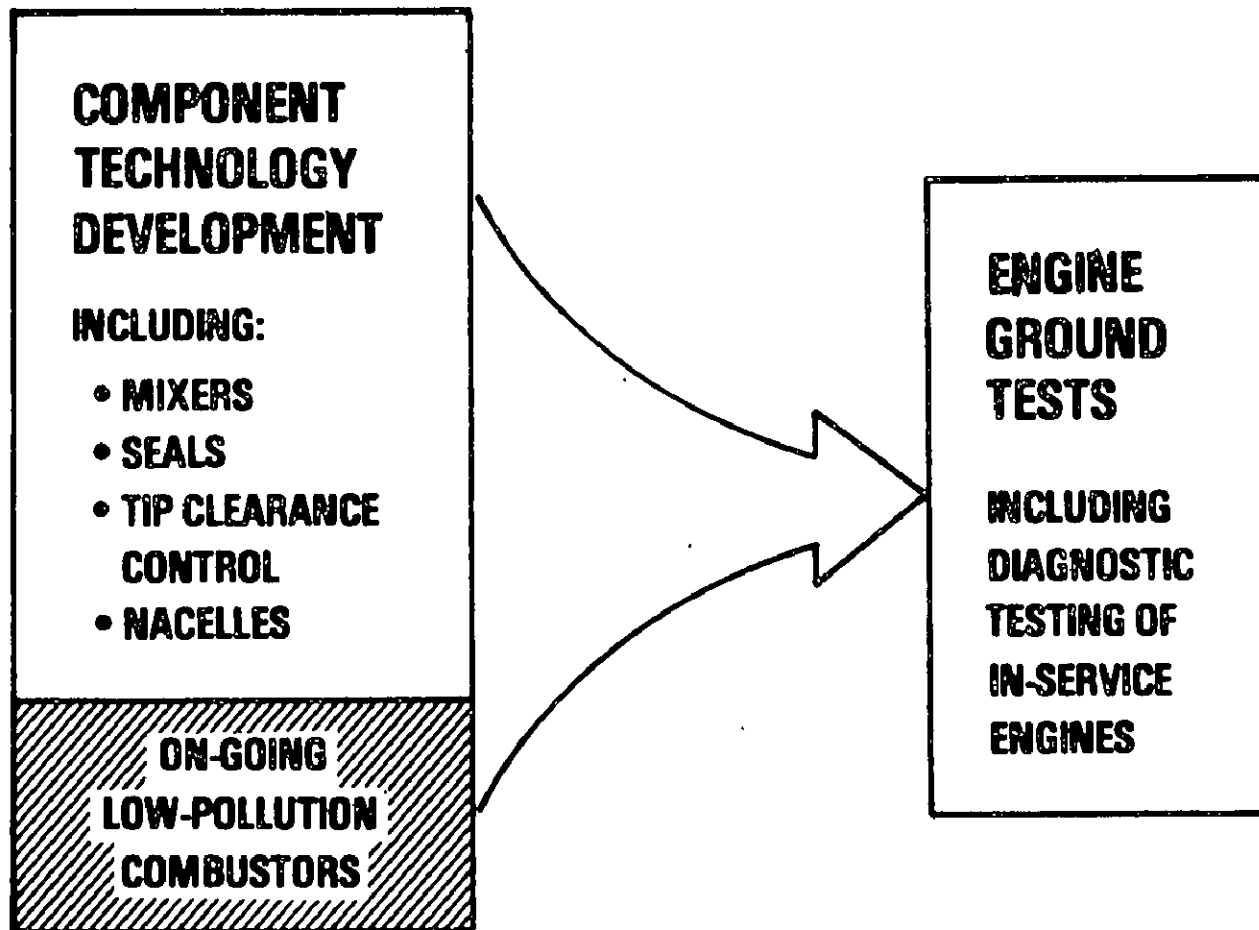


FIGURE 14

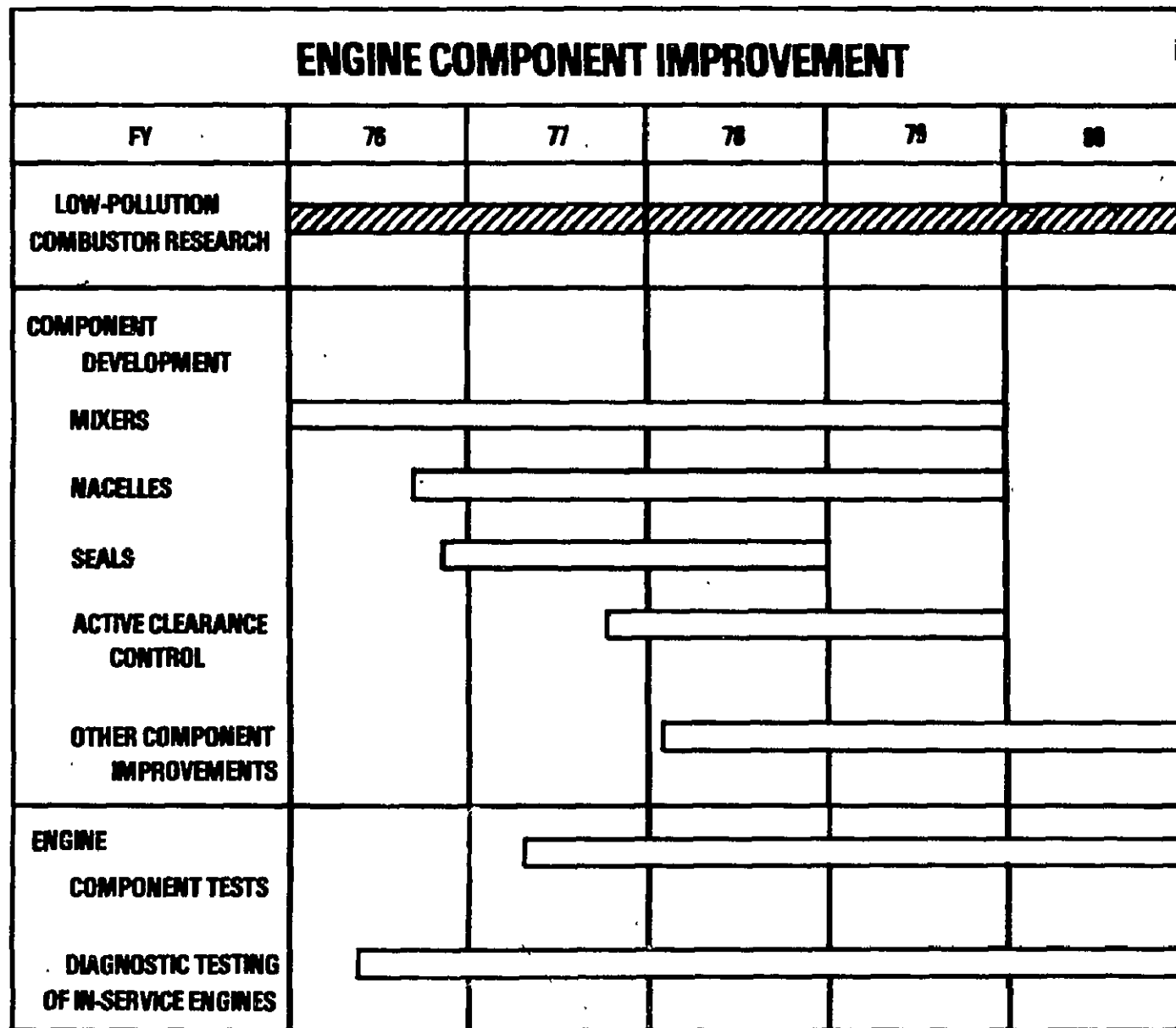


FIGURE 15

GROSS
R&D

ENGINE COMPONENT IMPROVEMENT

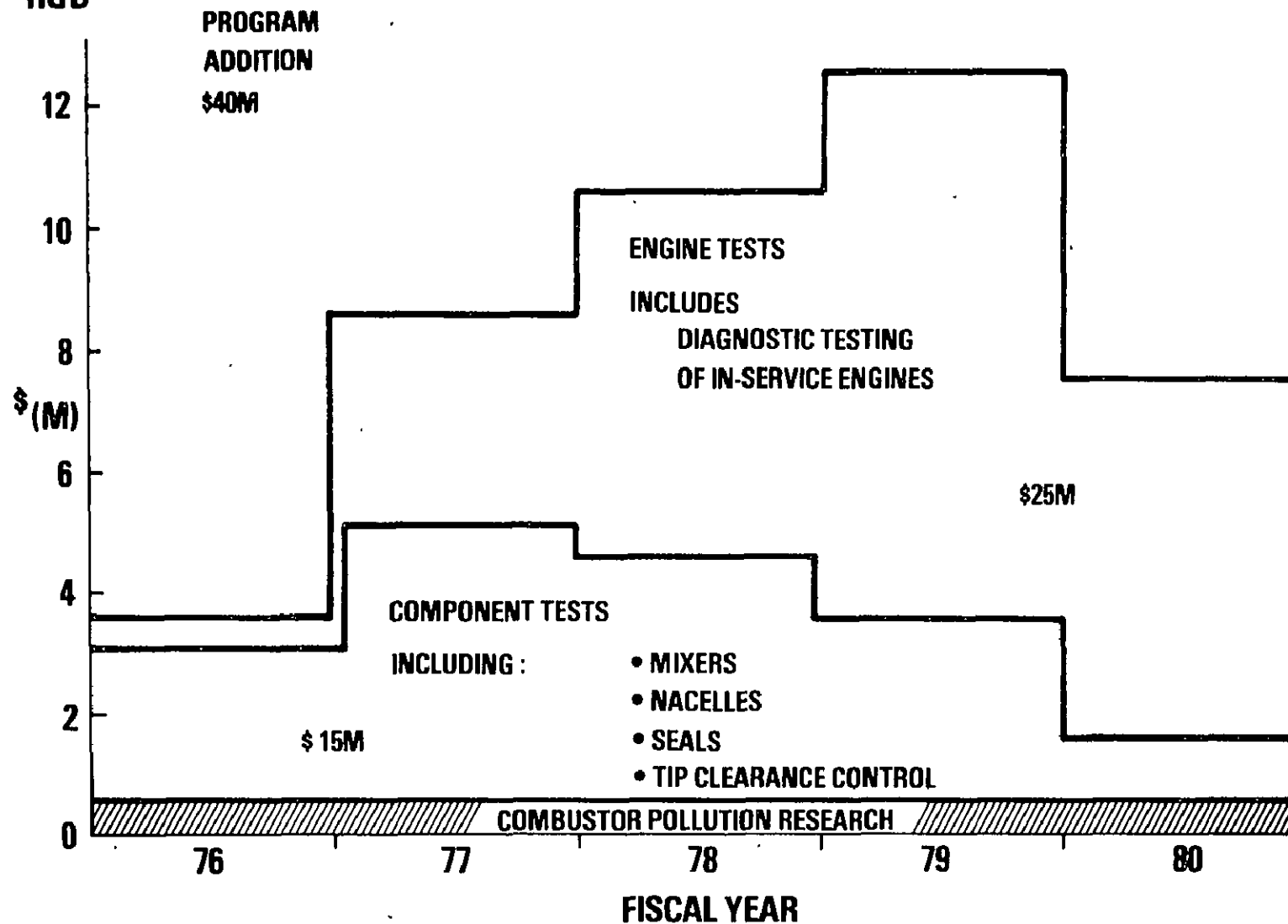


FIGURE 16

ENGINE COMPONENT IMPROVEMENT COMMENTS

ADVISORY BOARD

- HIGH PRIORITY WITH GREATEST POTENTIAL FOR NEAR-TERM FUEL SAVINGS
- INCLUDE DIAGNOSTIC TESTING OF IN-SERVICE ENGINES
- INCREASE EARLY-YEAR AND TOTAL FUNDING
- PROVIDE MORE RESOURCES FOR ENGINE TESTS AND BEGIN EARLY

ASEB

- APPROPRIATE AND WORTHWHILE ACTIVITY

FIGURE 17

NASA HC RA76-340(3)
6-13-75

Fuel Conservative Engine

CONCEPT

- o Explore the potential of advanced technology turbofans and unconventional propulsion concepts to reduce energy requirements for future aircraft. See Figure 18.

Advances in the technologies of all of the engine components coupled with proper selection of the design parameters can lead to major improvements in overall efficiency. However, these component improvements must not be at the expense of reliability, safety, environmental impact and general economy of operation, or cause unacceptable weight or drag penalties. In addition to the optimization of conventional turbofans and/or turboprops, unconventional concepts such as regeneration may offer further reductions in fuel consumption.

FUEL SAVINGS

- o 10-15% relative to the technology now available.

Figure 19 illustrates the fact that improvements can be made in engine specific fuel consumption either through increases in the cycle pressure ratio and temperature or through unconventional concepts such as regeneration. Tradeoffs will be required between the increased cost and maintenance of the higher temperatures and pressures of the advanced turbofan and the added weight and complexity of unconventional cycles.

IMPLEMENTATION

NASA, the engine manufacturers, and the Department of Defense have a continuing research and technology program to advance all the component technologies associated with engine design. The purpose of the proposed program is to supplement the baseline activities with new efforts that are especially pertinent to fuel conservation and to accelerate the process of making these technologies ready for application of future engines.

PROGRAM

The Fuel Conservative Engine program is conceptually illustrated in Figure 20. Optimization and sensitivity studies (including airframe integration and overall mission analyses) of advanced turbofans and unconventional variants such as regenerative or intercooled systems will be performed. Improvements in efficiency and/or reductions in weight will be sought in all component areas. Components to be studied include: fans, high-temperature turbines, improved materials and structures (including composites in blades, frames, and nacelles), and heat exchangers (for regenerators and intercoolers).

This development will augment a substantial on-going NASA effort in the areas of propulsion component and material research. This on-going effort includes the Advanced Multi-Stage Axial-Flow Compressor (AMSAC) program and the Materials for Advanced Turbine Engines (MATE) program.

These component development efforts will lead to an intensive engine-directed component development effort accompanied by detailed design studies. The engine-directed developments will be supported by advances made in the Engine Component Improvement Program already described. Supplementary engine-directed component development work is defined as part of the Level II program.

Depending on the results of the studies and the component research, a decision will be made whether to undertake an experimental engine program and the type of engine to be constructed and ground-tested. A schedule of activities for the three-phase Fuel Conservative Engine program is given in Figure 21.

The funding for the current NASA program and the additional effort described here is shown in Figure 22. The additional program would add a total of \$175 million over a 7-year period. The program total greatly increases the scope and intensity of the component program and would add an experimental engine in the 1980 time period.

By 1983 the new technologies described here will be demonstrated through component tests and ground tests of an advanced experimental engine and will be ready for application to new engine design. It is estimated that a new engine could be ready for use on new transports which could be introduced into service in the 1990-1995 time period.

COMMENTS

The program received substantial industry support by the engine and airframe manufacturers. The airlines emphasized the importance of reliability and maintainability in any advanced technology that is likely to be implemented. A summary of the comments is given in Figure 23.

FUEL CONSERVATIVE ENGINE

CONCEPT

**EXPLORE THE POTENTIAL OF ADVANCED TECHNOLOGY
TURBOFANS AND UNCONVENTIONAL PROPULSION CONCEPTS
TO REDUCE ENERGY REQUIREMENTS FOR FUTURE AIRCRAFT.**

FUEL SAVINGS

10% RELATIVE TO BEST CURRENT TECHNOLOGY.

BASIS FOR TECHNOLOGY READINESS

COMPONENT DATA AND EXPERIMENTAL ENGINE DEMONSTRATION

ADVANCED ENGINE CYCLES

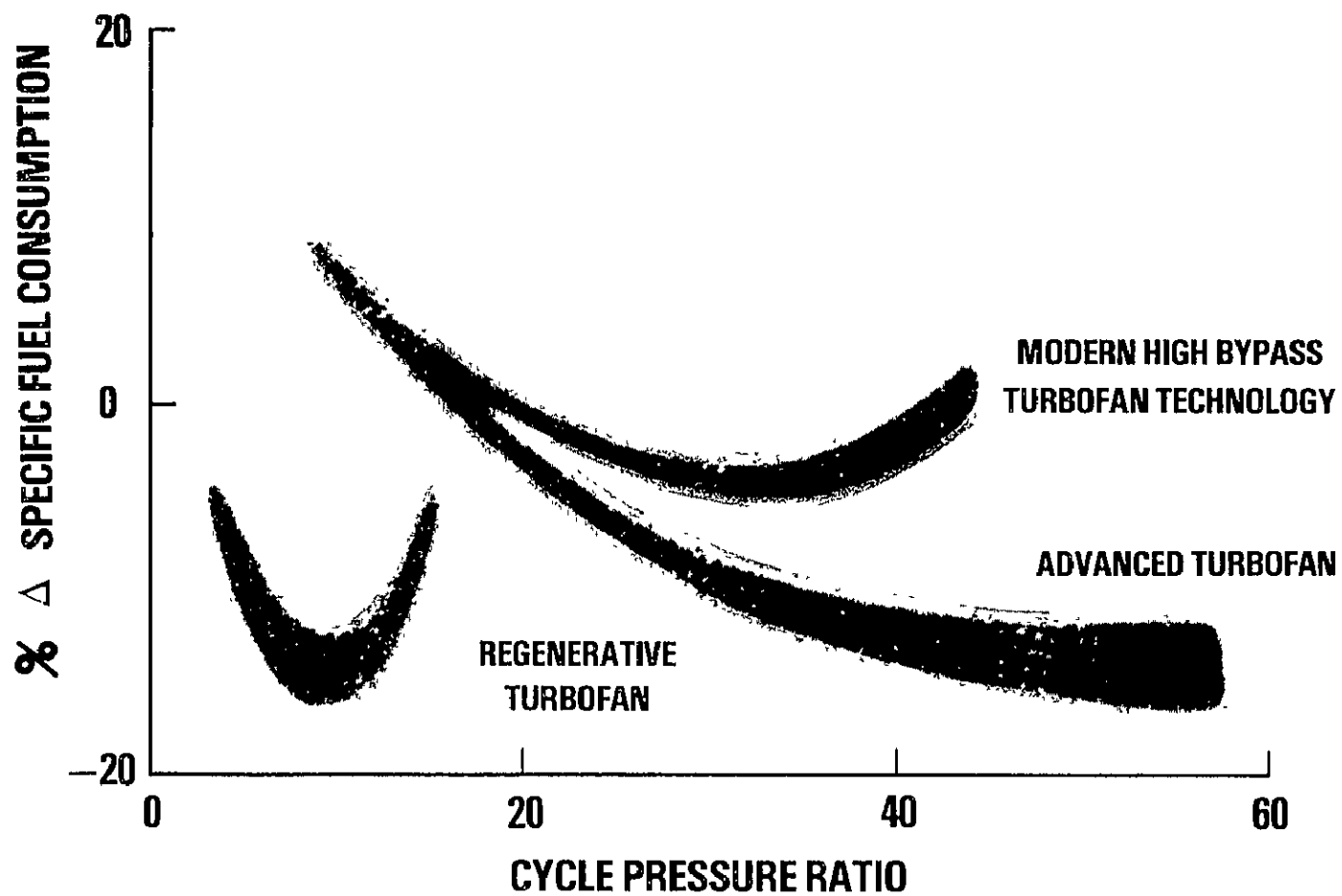


FIGURE 19

FUEL CONSERVATIVE ENGINE

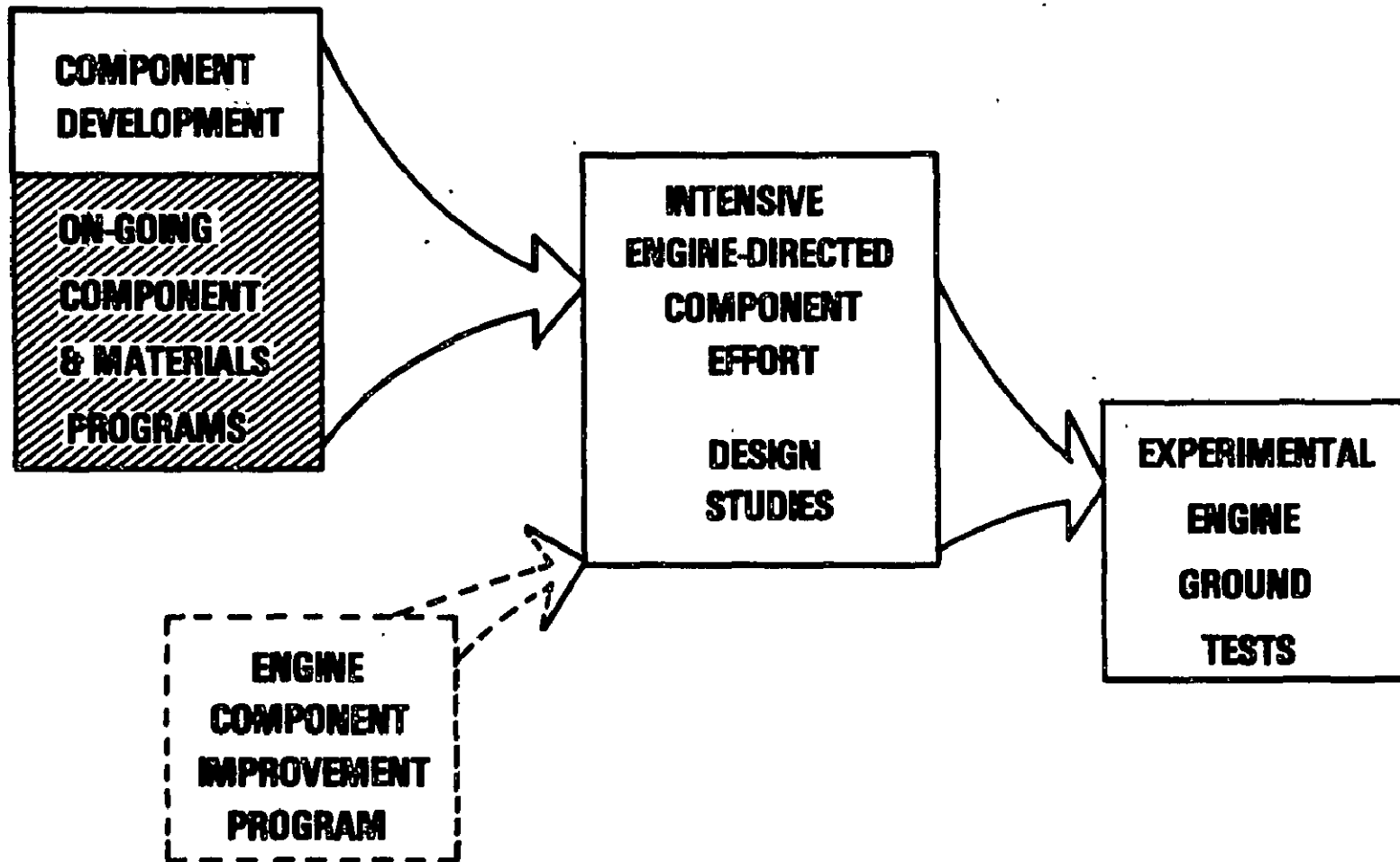


FIGURE 20

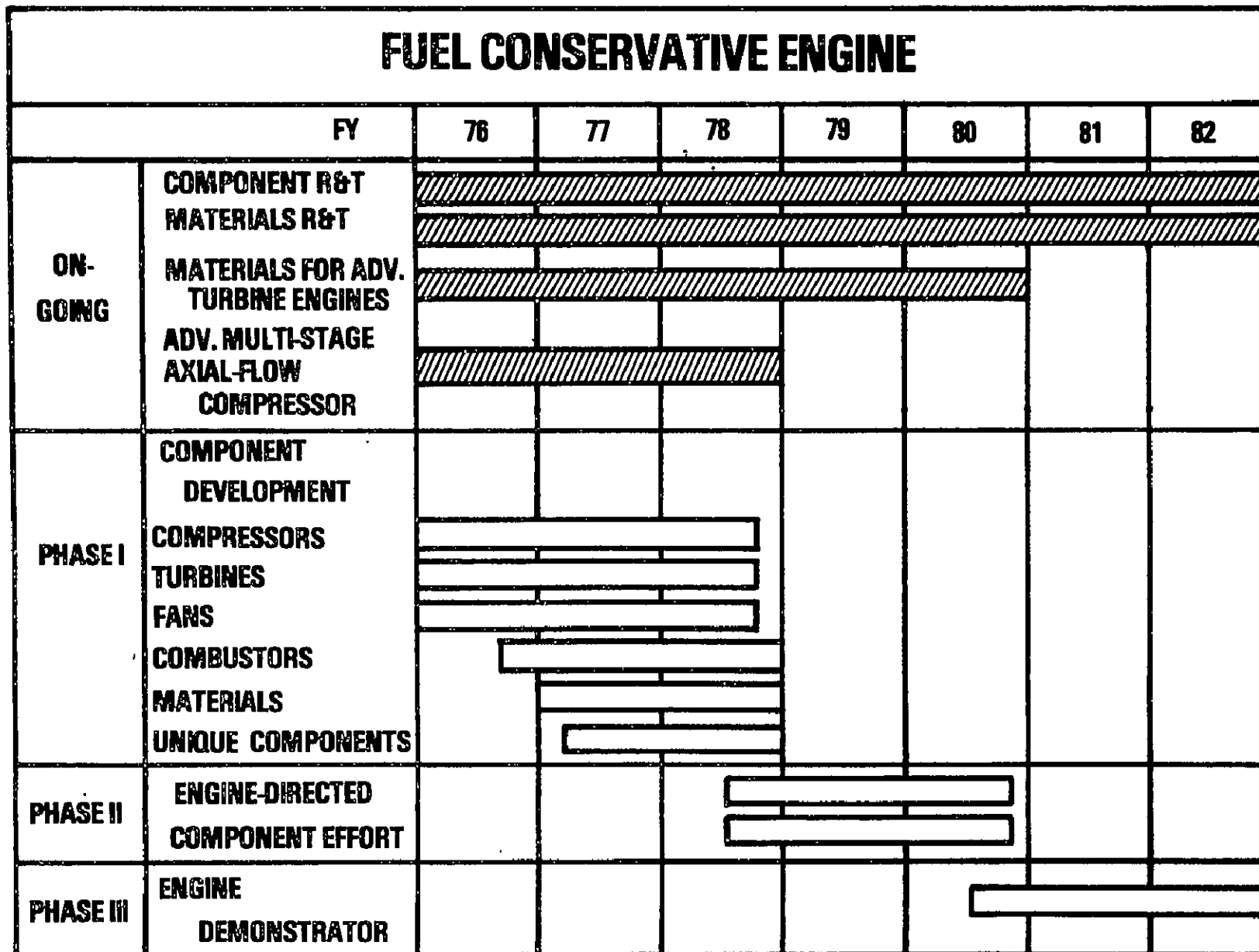


FIGURE 21

FUEL CONSERVATIVE ENGINE

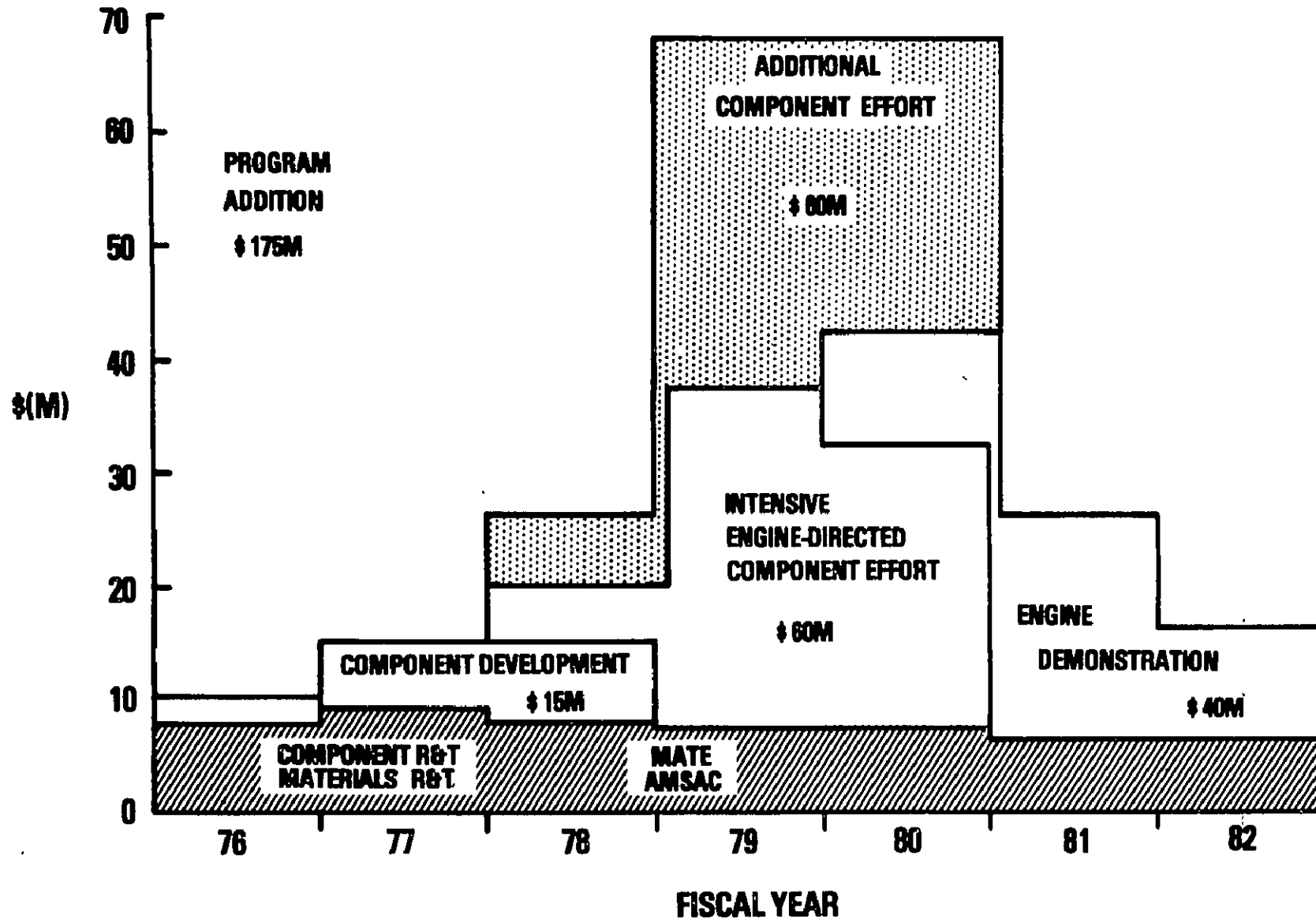


FIGURE 22

FUEL CONSERVATIVE ENGINE COMMENTS

ADVISORY BOARD

- LARGER EFFORT REQUIRED IN EARLY YEARS
- EVOLUTIONARY GAINS ARE SURE TO COME
- BE CONCERNED ABOUT THE EFFECT OF LARGE INCREASES IN CYCLE PRESSURES AND TEMPERATURES ON PERFORMANCE DETERIORATION
- ENGINE DEMONSTRATOR IS REQUIRED
- COORDINATE WITH DOD ENGINE PROGRAMS

FIGURE 23

Turboprop

CONCEPT

- o Demonstrate acceptable performance and passenger comfort of a Mach 0.8, 30,000 ft. cruise turboprop propulsion system. See Figure 24.

Turboprops were introduced into commercial service a generation ago but were supplanted by jets, except in some smaller aircraft. The jet-powered aircraft swept the market as a result of higher speed, above-the-weather capability, enhanced passenger comfort, and simpler maintenance. In an era of cheap fuel, energy consumption was not a factor, and higher productivity coupled with passenger appeal made jets the universal choice for the major airlines. Nevertheless, the higher propulsive efficiency of the propeller offers the prospect of reduced fuel consumption, and the application of advanced technologies may also now provide comparable cruise speeds and other desirable characteristics of current turbofan-powered transports. Estimates by the Department of Defense (Figure 25) show that the Russian turboprop transports have already achieved high propeller efficiency at cruise speeds approaching those of current jet-powered transport aircraft.

FUEL SAVINGS

- o 15-20% savings over turbofan engines.

When installed in airplanes cruising at Mach number 0.8 and altitudes above 30,000 feet, it is estimated that a new-design turboprop (or "prop-fan") will offer a 15-20% savings in fuel usage compared to a turbofan employing the same level of technology in the core (Figure 26). If a lower flight speed were acceptable, the savings would be even greater.

IMPLEMENTATION

Because of the perception of turboprops as an old-fashioned, troublesome device with no passenger appeal, the airlines and the manufacturers have little motivation to work on this engine type. However, with the primary goal of reducing the nation's consumption of energy, it is an appropriate role for NASA to assess and advance the technologies that would permit the development of a high speed fuel-conservative turboprop.

This program is structured to advance propeller aerodynamics and structures to attain high-speed, high-loading designs that couple high efficiency with low levels of cabin noise and vibration. This will be demonstrated through component tests, ground tests of an experimental engine, based on an existing or modified core, and in-flight evaluation at Mach 0.8. Technology readiness for the design for new turboprop propulsion systems is expected by about 1984.

PROGRAM

This program is divided into four-phases shown conceptually in Figure 27. The program will accomplish the following tasks:

- (1) Perform system studies by engine-airframe-airline teams to determine the potential of turboprop airplanes, identify desirable designs, and assess technology deficiencies. Advance the understanding of aerodynamics relevant to high-speed, highly-loaded propellers, nacelles, and air-frame interactions. Conduct wind-tunnel tests on integrated propeller/airframe combinations.

- (2) Advance the technology of structures materials, and the dynamics of blades for use on these propellers. Develop components to be applied in an experimental turboprop based on an existing or modified core engine. Component development would include blades, rotor systems, gear boxes and engine controls. The configuration of an experimental engine will be defined.

- (3) Integrate engine components and core. Perform engine ground tests, emphasizing propeller thrust, efficiency, noise, dynamics, and vibration.

- (4) Assess existing airframes compatible with the ground-tested propulsion system and suitable for a turboprop flight demonstration at Mach 0.8 and 30,000 feet altitude. Analyze the structural modifications required for the selected demonstration airplane. Modify airframe, install engines, and perform flight tests.

A decision point is reached at the end of each phase for evaluation of the overall program and determination of the scope of the next task. A schedule of these activities is given in Figure 28.

The estimated resource requirements are given by fiscal year and are divided by phases in Figure 29. A total program requirement of \$125 million is estimated over a nine year period. A \$50 million flight test demonstration is included in the Level II program. Successful completion of all phases of this program would result in the demonstration, by 1984, of a turboprop-powered airplane with cruise speed and altitude capability comparable to today's turbofan-powered transports. Cabin environment and passenger comfort would also be as good as today's transports.

This technology could be applied to new transport aircraft designs which would be ready for introduction into service in the late 1980's and beyond.

COMMENTS

There was mixed reaction to the turboprop program described. Although there was disagreement as to the ultimate likelihood of implementation of a turboprop transport, there was endorsement for the early-phase exploratory efforts to determine the technical feasibility of high-efficiency, high-speed propellers. Commitment to further development was viewed as critically dependent on successful completion of the exploratory efforts. A summary of advisors' comments is given in Figure 30.

TURBOPROPS

CONCEPT

**DEMONSTRATE PERFORMANCE AND CABIN ENVIRONMENT
OF A TURBOPROP TRANSPORT FOR MACH .8 AT 30,000 FT.
ALTITUDE.**

FUEL SAVINGS

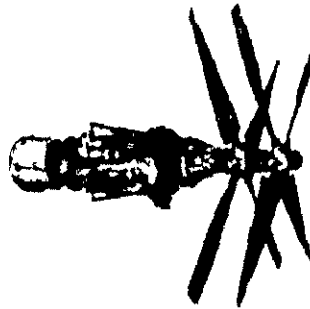
**15% OVER TURBOFANS WITH EQUIVALENT LEVEL OF CORE
ENGINE TECHNOLOGY.**

BASIS FOR TECHNOLOGY READINESS

**TESTS OF CRITICAL COMPONENTS AND POSSIBLE FLIGHT
DEMONSTRATION.**

FIGURE 24

LONG RANGE TURBOPROPS



KUZNETSOV NK-12M
15,000 SHP



TUPOLEV TU-95 "BEAR"

GROSS WEIGHT	340,000 LB
MAX RANGE	7,800 MILES
PROP DIAMETER	18.4 FT
$\frac{\text{SHP}}{D^2}$	44 (T.O.)
PROP η 82% (0.75M CRUISE)	



ANTONOV AN-22 "COCK"

GROSS WEIGHT	550,000 LB
MAX RANGE	6,800 MILES
PROP DIAMETER	20.3 FT
$\frac{\text{SHP}}{D^2}$	35 (T.O.)
PROP η 86% (0.69M CRUISE)	

FIGURE 25

FUEL PER PASSENGER - MILE

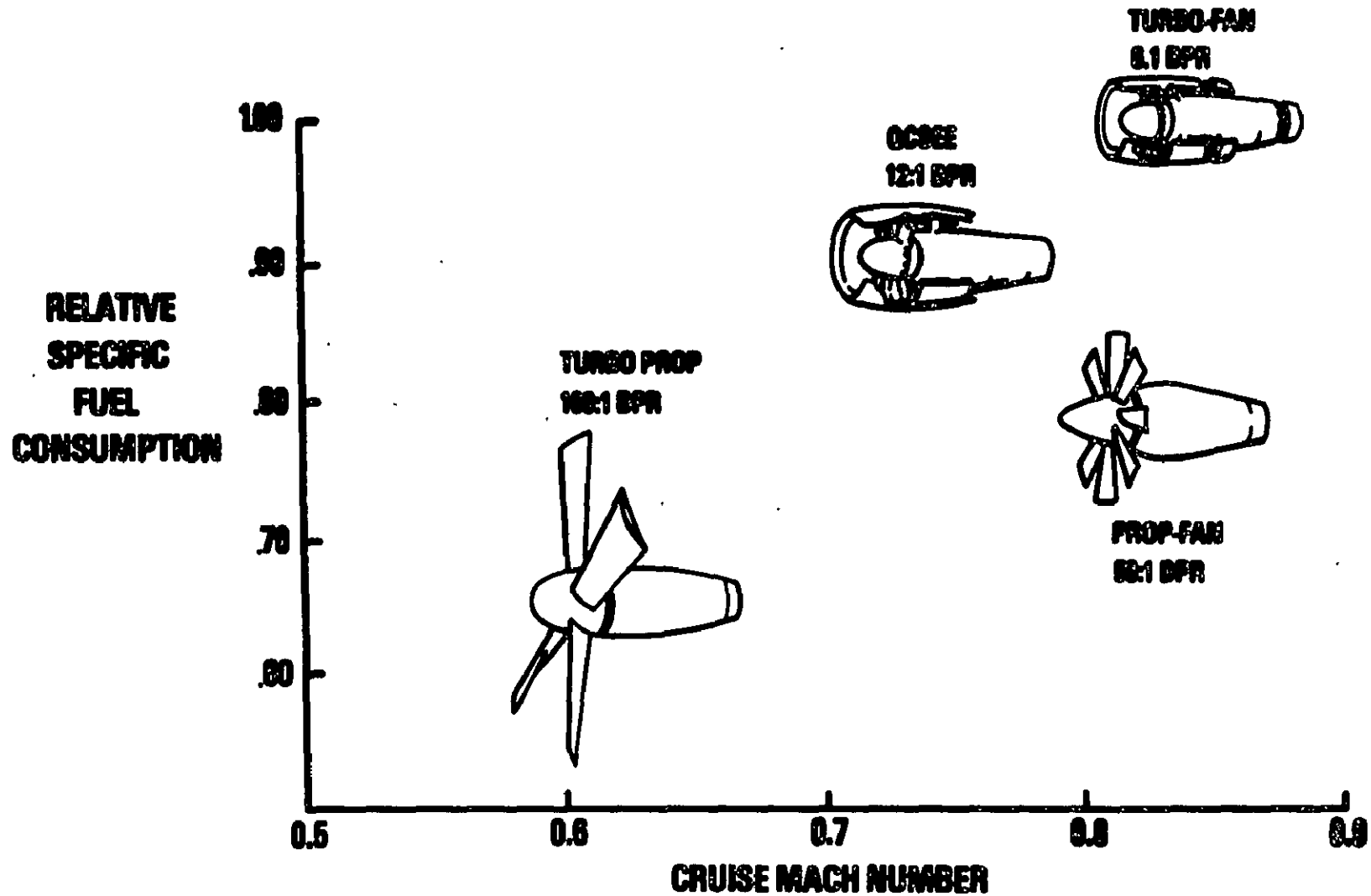


FIGURE 26

TURBOPROPS

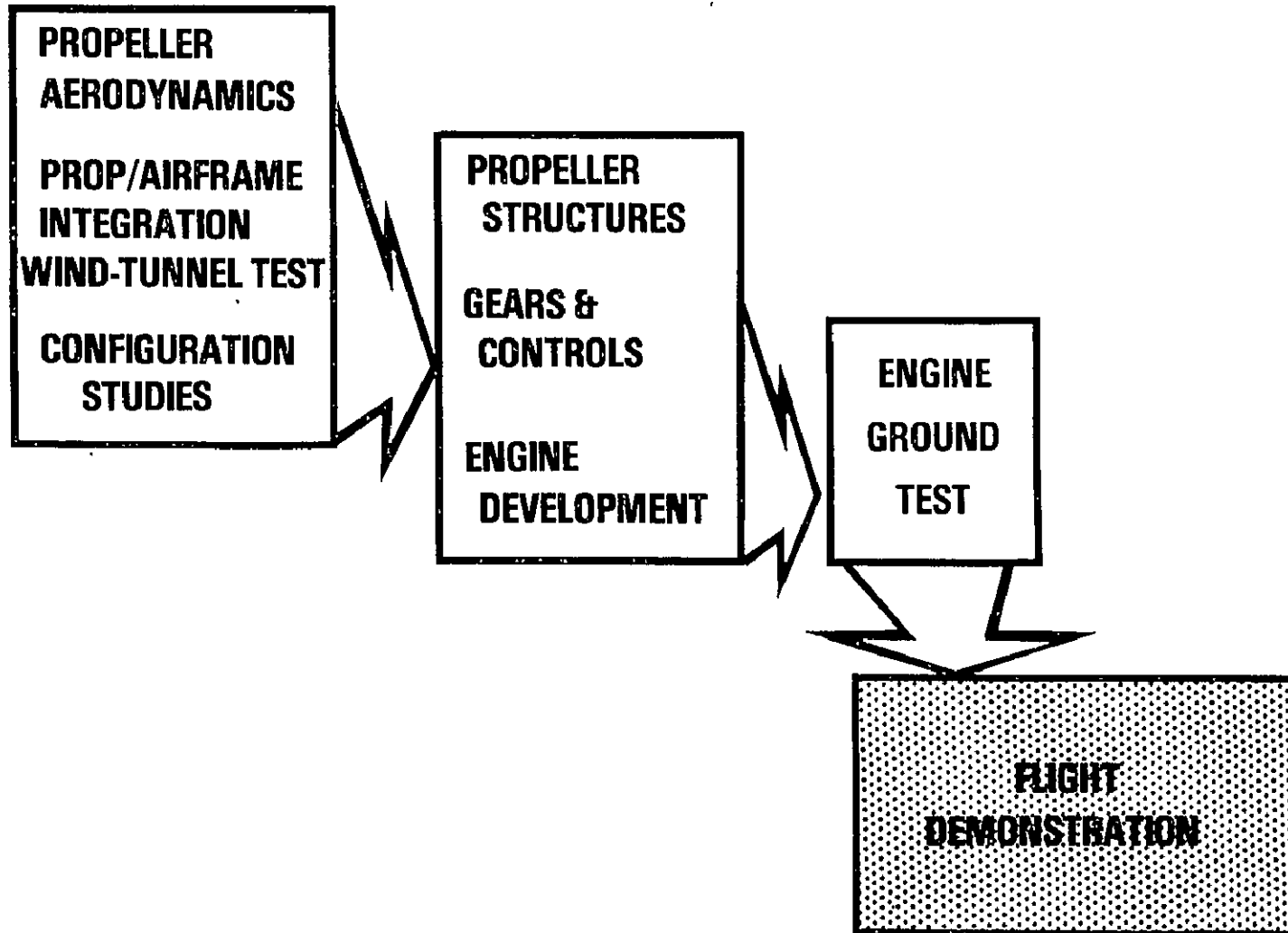


FIGURE 27

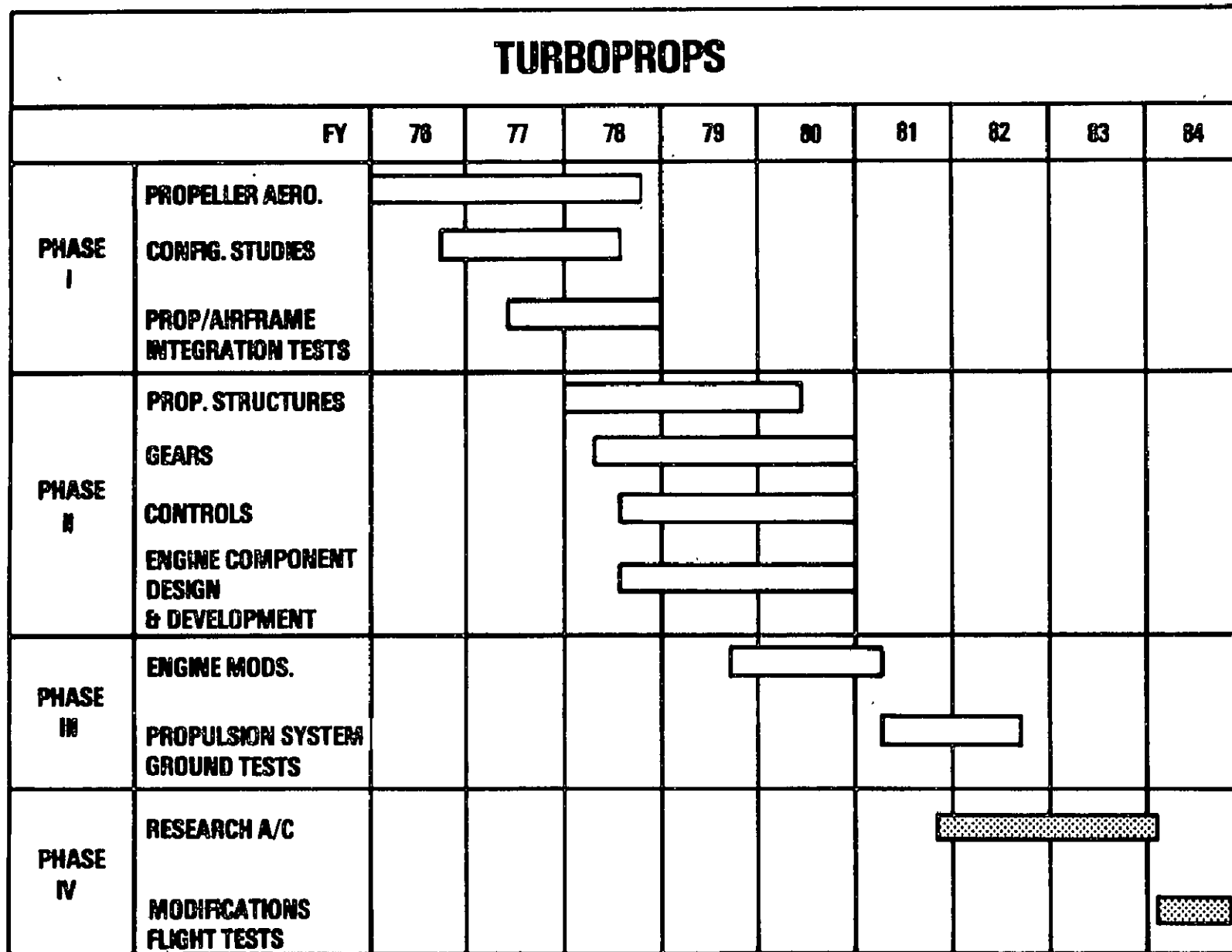


FIGURE 28

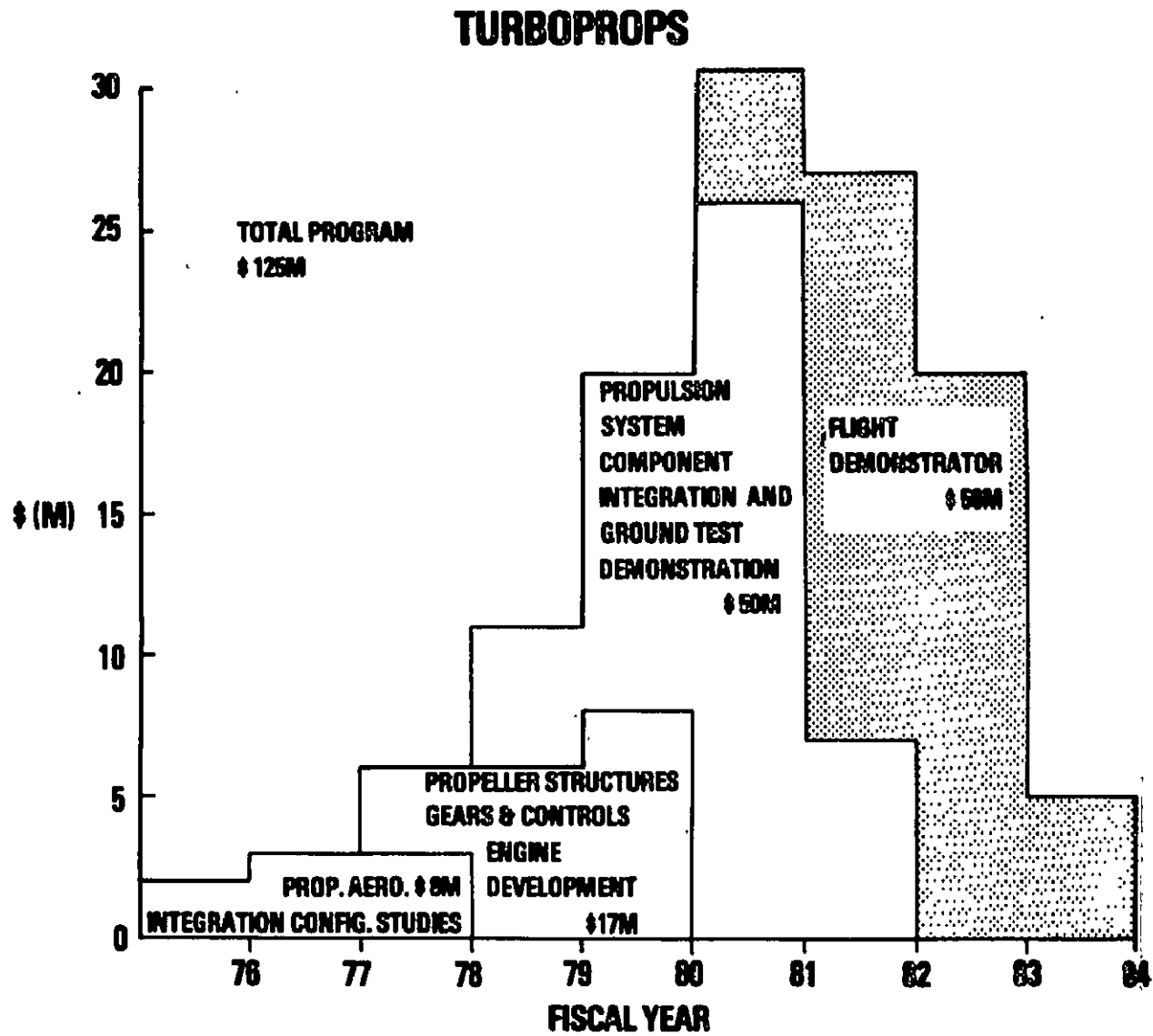


FIGURE 29

TURBOPROP **COMMENTS**

ADVISORY BOARD

- PHASE I EFFORT ENDORSED BECAUSE OF HIGH POTENTIAL PAYOFF AND LACK OF INDUSTRY EFFORT
 - FOLLOW-ON PHASES DEPEND CRITICALLY ON SUCCESS IN PHASE I
 - ENGINE DEVELOPMENT EFFORT REQUIRED BEFORE ENGINE GROUND TEST PHASE
 - INVOLVE AIRLINE OPERATORS EARLY TO ENSURE THAT PRACTICAL PROBLEMS SUCH AS MAINTENANCE, SAFETY, AND RIDE QUALITY ARE PROPERLY ADDRESSED.
-
- CONDUCT A PAPER STUDY TO IDENTIFY POTENTIAL PAYOFF
 - TECHNOLOGY ADVANCEMENT MUST PRECEDE FLIGHT DEMONSTRATION
 - AIRLINE ACCEPTANCE IS MAJOR PROBLEM

AERODYNAMICS

The Task Force considered a large number of potential improvements to the aerodynamic efficiency of aircraft from which four areas of activity were identified. These activities and their applications are shown in Figure 31. Elements from these four areas of activity were developed into two specific programs: the Fuel Conservative Transport program and the Laminar Flow Control program.

The Fuel Conservative Transport program is aimed at the evolutionary improvement of aerodynamic design and the development of active controls technology. These advances would allow optimized aircraft designs based on increased fuel prices and provide the technology base for such designs. Two areas of activity illustrated in Figure 31, winglets and drag cleanup, were not developed as specific programs but were included in the Fuel Conservative Transport program.

Winglets, illustrated in Figure 32, are small vertical surfaces mounted at the tip of the main wing and canted slightly outward. They act as lifting surfaces in the cross-flow of the wing and are carefully designed to produce a net forward thrust. Previous calculations and wind tunnel model tests have shown the potential of a 4 - 6% fuel savings for winglets if retrofitted to current transports. The Fuel Conservative Transport program will continue to evaluate this concept. NASA has been supporting the Air Force in evaluating the potential use of winglets on military transport aircraft and will continue such support.

Based on the strong recommendation of the Aeronautics and Space Engineering Board of the National Research Council, the Fuel Conservative Transport program will include consideration of the feasibility of identifying and reducing sources of drag on existing aircraft as a technique for near-term fuel savings. The Task Force has been unable to structure a specific program in this area because of complex considerations of proprietary data and corporate competitive positions. However, NASA facilities and expertise will be made available to companies requiring help in drag-cleanup research on existing aircraft.

The second program element under Aerodynamics is the Laminar Flow Control program. Significant fuel savings would result from the development of a practical, reliable, and maintainable system to remove surface boundary layers by suction in order to maintain laminar flow. Flow

laminarization results in large reductions in drag and therefore in fuel requirements. This is a high payoff area but because of its high risk and long development time, it is not being pursued by industry. Thus it is a most appropriate area for NASA involvement.

The two aerodynamics programs developed by the Task Force will be described in detail in the following sections.

AERODYNAMICS

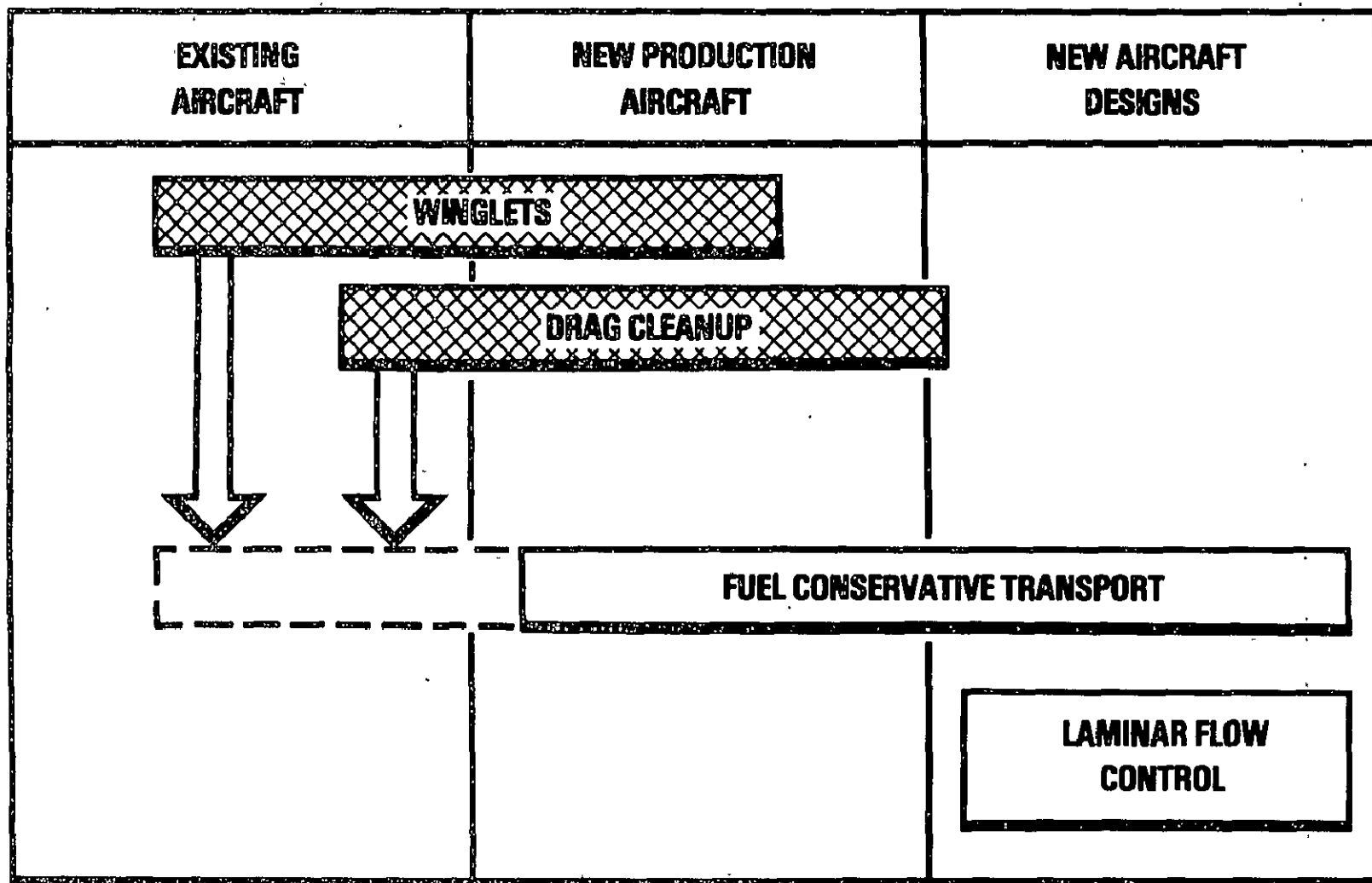


FIGURE 31

WINGLETS

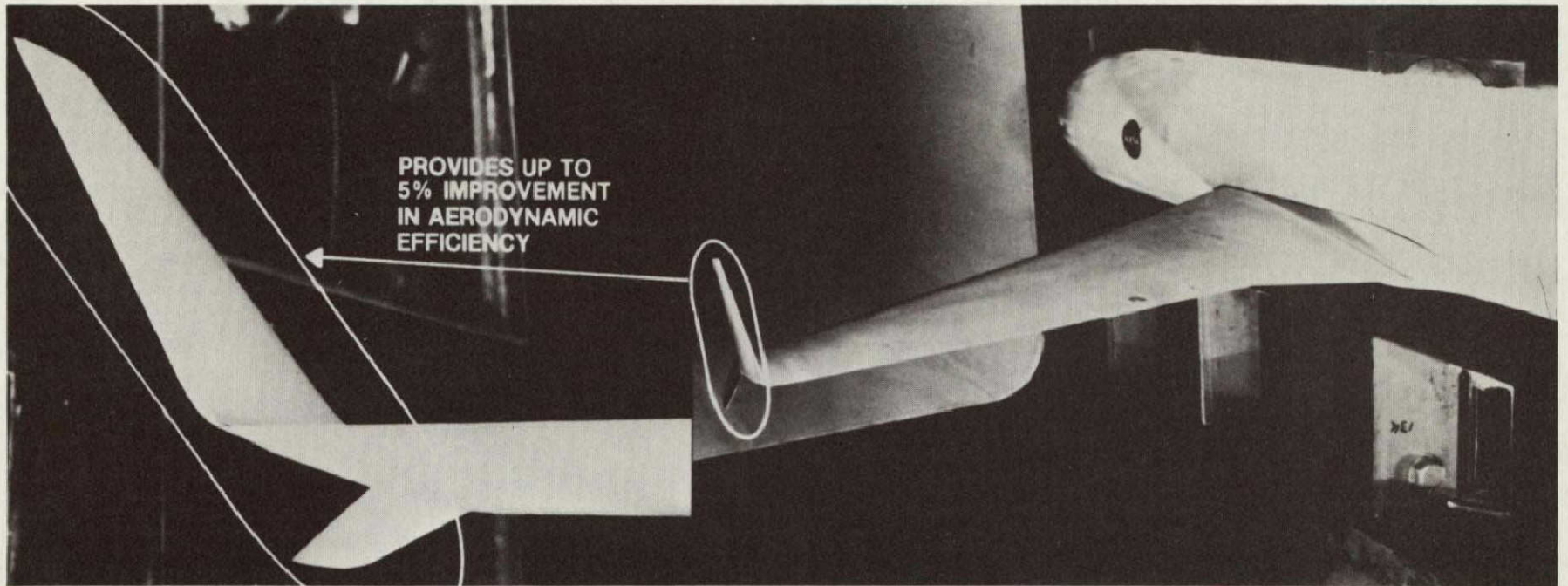


FIGURE 32

Fuel Conservative Transport

CONCEPT

- o Demonstration of the fuel conservation potential of advanced aerodynamic technology, improved propulsion system integration, and the incorporation of active controls in aircraft design. See Figure 33.

Supercritical aerodynamic concepts were originally developed to delay the onset of transonic drag rise for high-subsonic-speed transports. The application of this technology to the design of a transport with a cruise Mach number of 0.8 permits higher aspect ratio and lower wing sweep, with a corresponding improvement in lift-to-drag ratio and fuel consumption at no weight penalty (Figure 34). The advanced aerodynamic concepts must be carefully integrated with the propulsion system to minimize the penalties of conventional and unconventional installations. Use of active controls permits relaxation of critical design constraints for static stability margins. Active controls may also be applied in some designs for gust and maneuver load alleviation and improved passenger ride comfort. See Figure 35.

FUEL SAVINGS

- o 10 - 20%

The fuel savings from advanced aerodynamic technology is estimated at approximately 10-15% as compared to the technology incorporated in the current wide-body transports. In addition, the use of active controls which would allow designs with reduced static stability margins would result in a 5% fuel savings.

IMPLEMENTATION

Supercritical aerodynamic concepts have been extensively investigated in wind tunnels and flight tested on several aircraft (F-8, T-2C, F-111). There is a need to develop a broader experimental data base, particularly for off-design conditions, and to improve and validate three-dimensional wing design procedures in order for the airframe manufacturers to employ these

produced in 1985 and beyond. It is also possible that some aerodynamic changes could be incorporated in the design of derivatives of currently produced aircraft.

COMMENTS

The advisors strongly support NASA involvement in the areas of advanced wing technology, propulsion/airframe integration and active controls. The extent to which NASA carries the development, however, was not universally agreed upon. It was generally felt that NASA should stop short of flight testing a completely reoptimized new airplane. A summary of the advisors' comments is given in Figure 39.

FUEL CONSERVATIVE TRANSPORT

CONCEPT

**DEMONSTRATE THE FUEL CONSERVATION POTENTIAL OF
ADVANCED AERODYNAMIC TECHNOLOGY, IMPROVED PROPULSION
SYSTEM INTEGRATION AND THE INCORPORATION OF ACTIVE
CONTROLS IN AIRCRAFT DESIGN**

FUEL SAVINGS

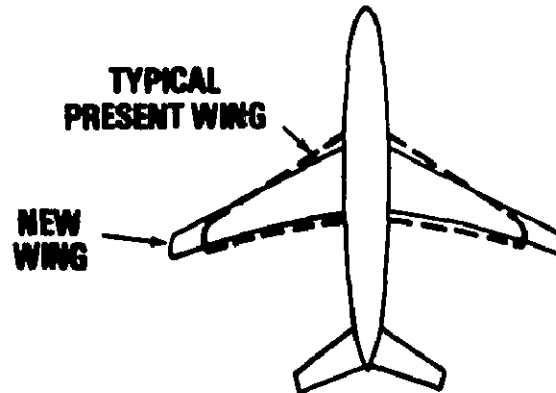
10 – 20% COMPARED TO CURRENT WIDE-BODY TRANSPORTS

BASIS FOR TECHNOLOGY READINESS

- **FUEL CONSERVATIVE AIRCRAFT DESIGN AND WIND-TUNNEL TESTS**
- **SELECTED FLIGHT DEMONSTRATIONS AS REQUIRED**

FIGURE 33

EFFECT OF SUPERCRITICAL WING ON FUEL CONSUMPTION



SUPERCritical WING FOR REDUCTION OF FUEL CONSUMPTION HAS:

- REFINED AIRFOIL SHAPE**
- INCREASED THICKNESS**
- GREATER SPAN**
- HIGHER DESIGN LIFT**
- REDUCED SWEEPBACK**

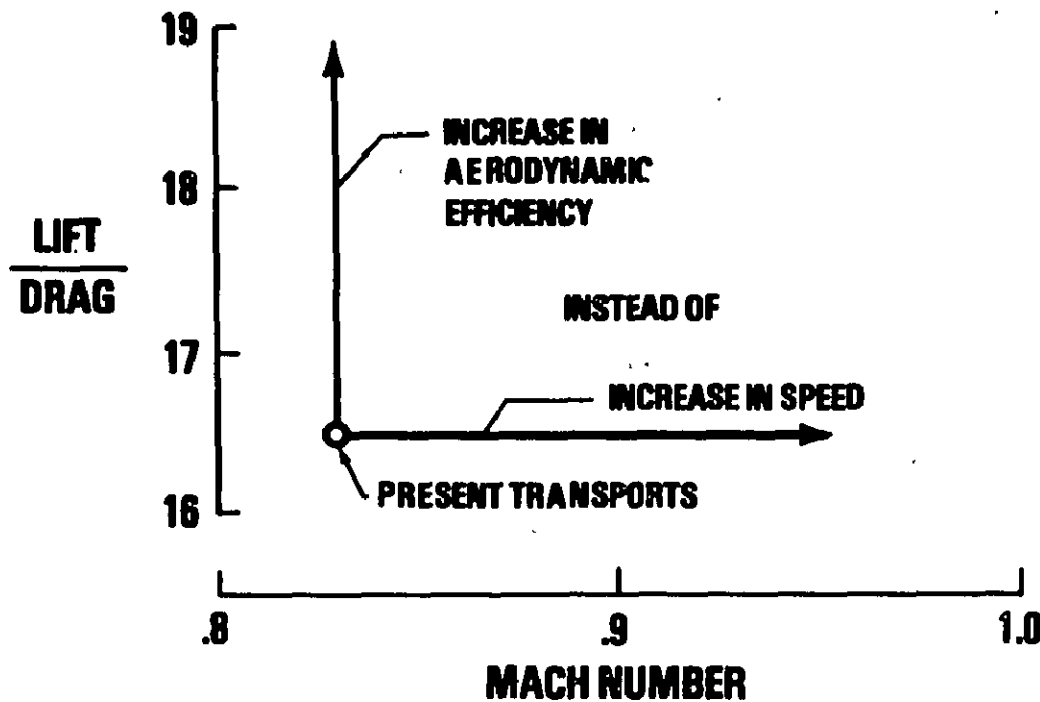
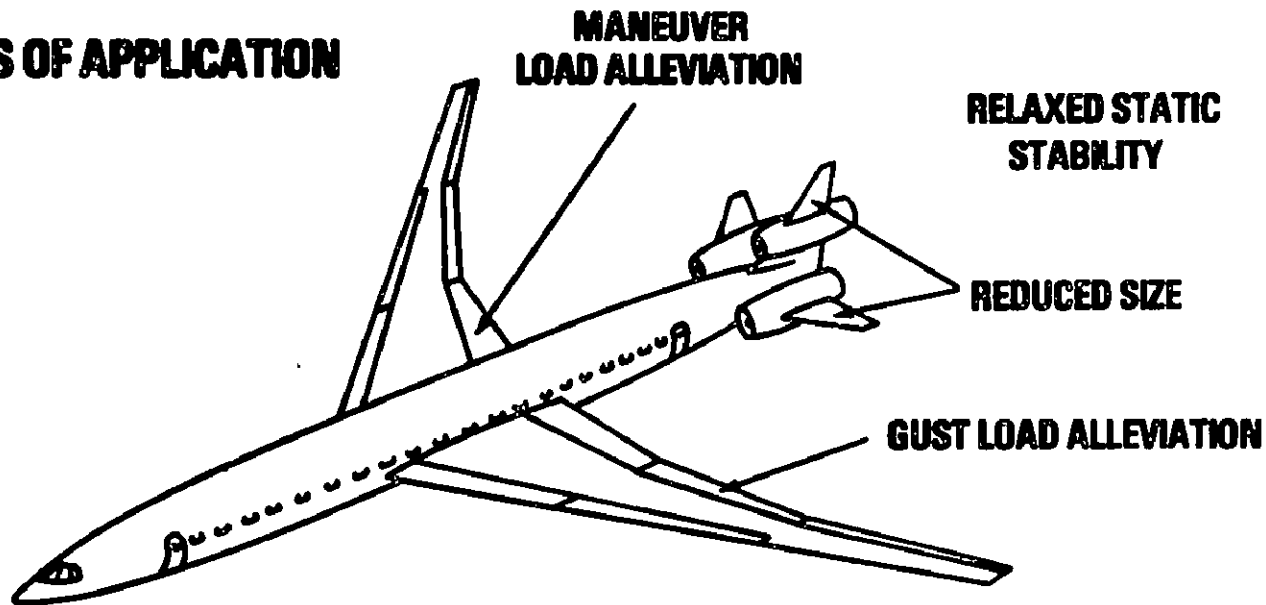


FIGURE 34

FLIGHT CONTROL SYSTEMS FOR FUTURE TRANSPORT AIRCRAFT

AREAS OF APPLICATION



PAYOFFS

- AIRCRAFT MORE EFFICIENT
- FATIGUE LIFE EXTENDED
- FLYING AND HANDLING QUALITIES IMPROVED
- RIDE SMOOTHER
- FUEL CONSERVATION

FIGURE 35

FUEL CONSERVATIVE TRANSPORT

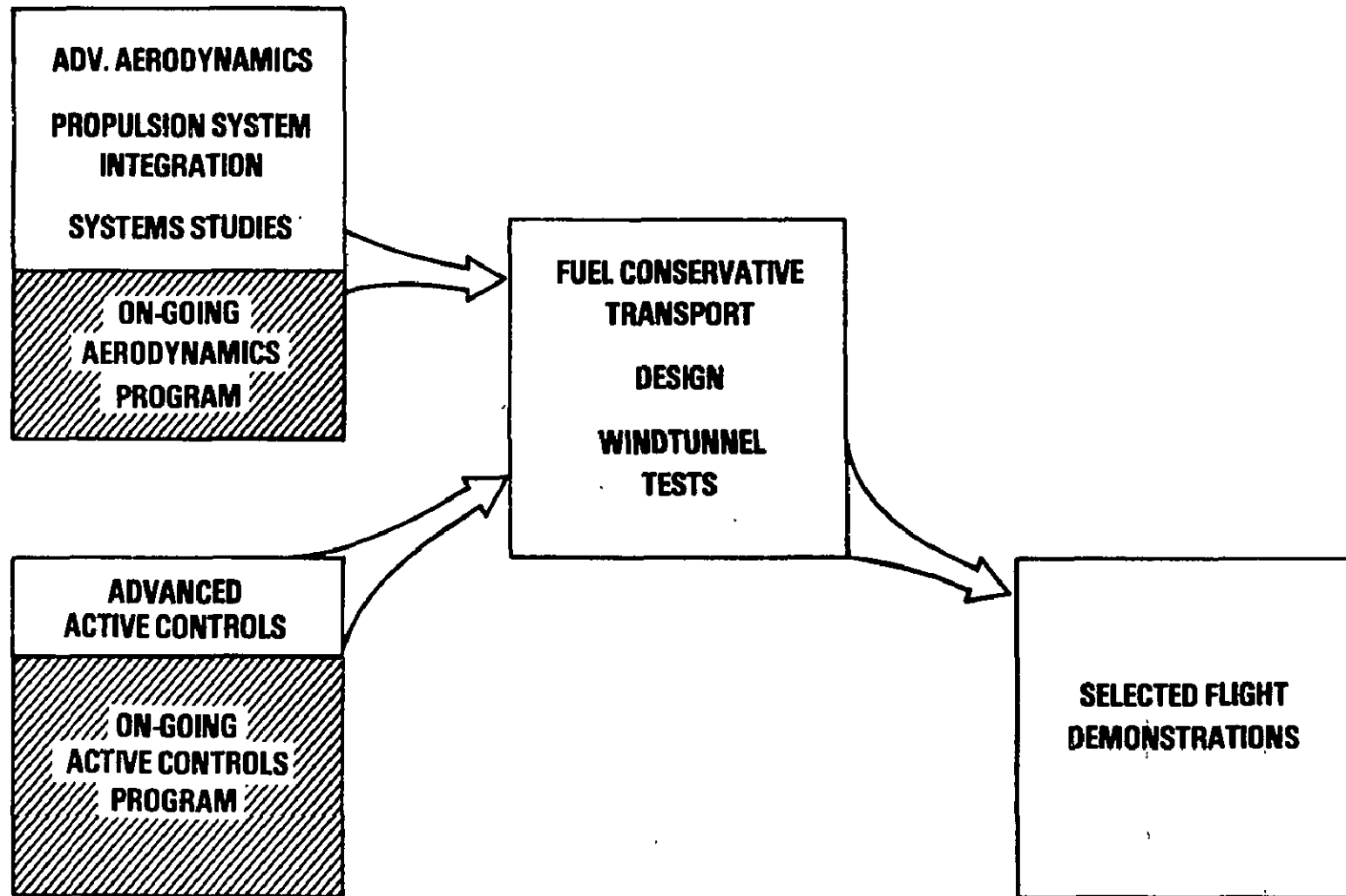


FIGURE 36

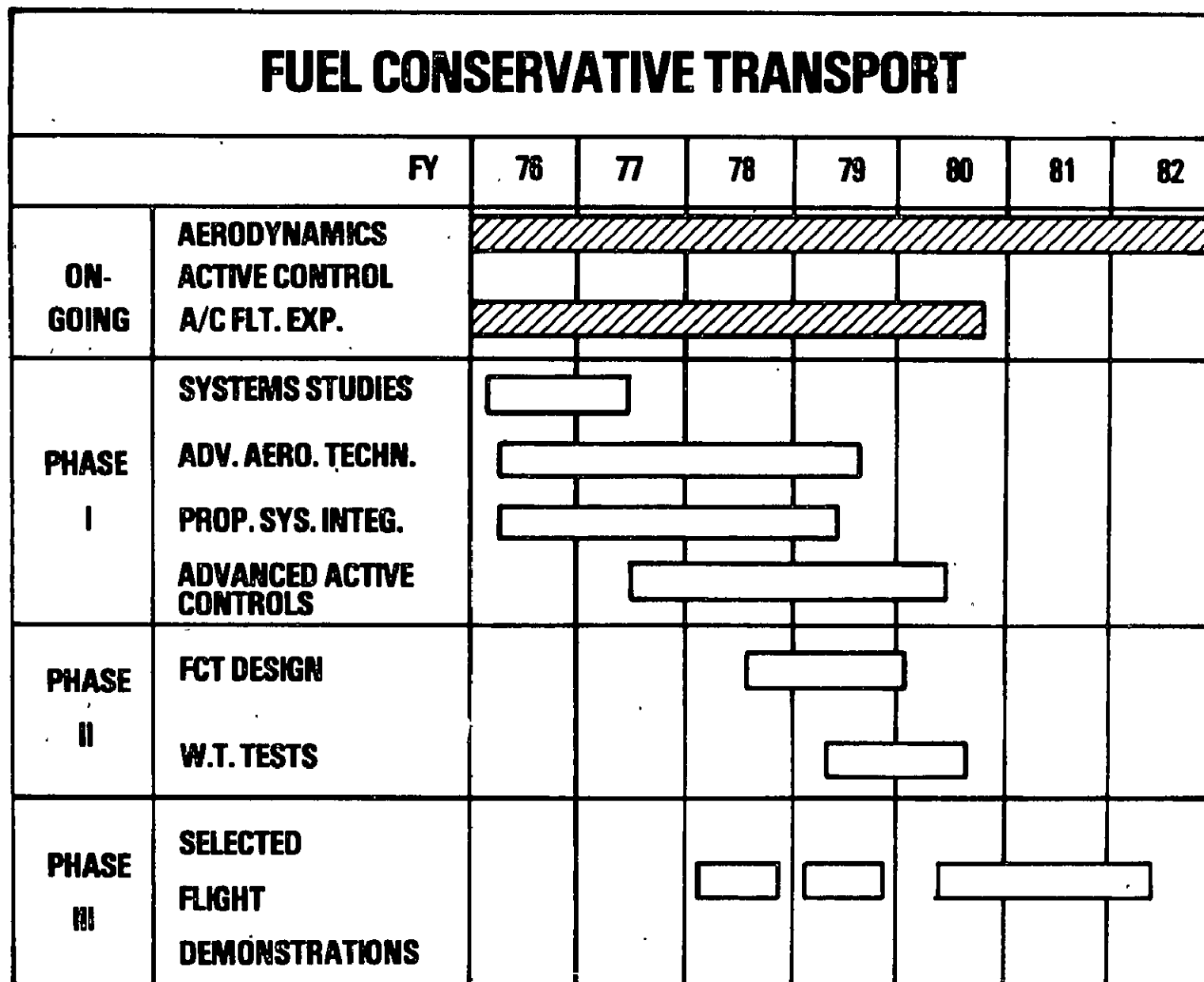


FIGURE 37

FUEL CONSERVATIVE TRANSPORT

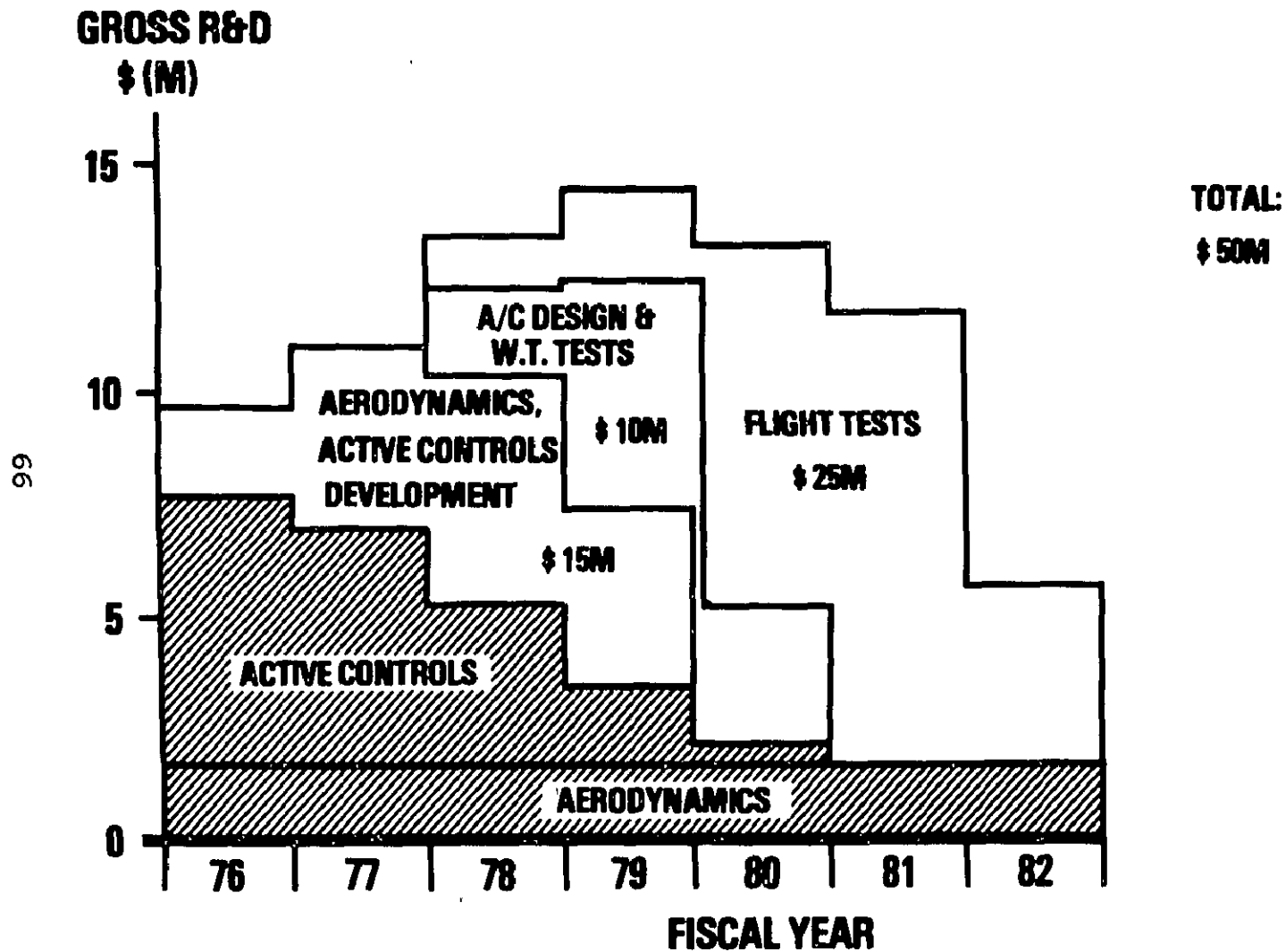


FIGURE 38

FUEL CONSERVATIVE TRANSPORT

COMMENTS

ADVISORY BOARD

- **EARLY EMPHASIS SHOULD BE ON ADVANCED WING TECHNOLOGY**
- **FLIGHT TEST OF AIRCRAFT INCORPORATING SEVERAL FUEL-SAVING TECHNOLOGIES NOT REQUIRED. AS HIGH-RISK TECHNOLOGY ITEMS ARE IDENTIFIED, FLIGHT VERIFICATION MAY BE NECESSARY.**
- **SHOULD CONSIDER FEASIBILITY OF IDENTIFYING AND REDUCING SOURCES OF DRAG ON EXISTING AIRCRAFT.**

ASEB

- **NASA STRONGLY URGED TO CONSIDER DRAG CLEAN-UP OF CURRENT AIRCRAFT. SIGNIFICANT POTENTIAL PAYOFF BECAUSE TECHNOLOGY CAN BE APPLIED IN NEAR TERM.**

FIGURE 39

Laminar Flow Control

CONCEPT

- o Develop and demonstrate a practical, reliable, maintainable boundary-suction system for viscous drag reduction. See Figure 40.

During cruise of subsonic transports approximately one-half of the total drag is composed of skin friction which is dependent on the nature of the boundary layer, i.e. whether it is laminar or turbulent. By maintaining laminar boundary layers, large skin friction reductions and fuel savings can be realized (Figure 41). The most effective means known to maintain laminar flow is by application of suction through slots or porous surfaces.

FUEL SAVINGS

- o 20-40% depending on extent of application and on airplane range.

Depending on the extent of application of laminar flow control to the aircraft, i.e., wings, tails, and fuselage, the estimated fuel savings range from 20 to 40 percent or more. Also, the longer the range of the aircraft the greater the fuel savings. These figures are relative to medium-to-long range aircraft designed without friction drag reduction.

IMPLEMENTATION

Early experiments with the USAF X-21A airplane (Figure 42) demonstrated that laminar flow could be consistently maintained, although the pumping and hardware systems were not developed to a cost-effective stage. Recent developments in other technologies, such as lightweight porous composites and pumping systems, provide the promise of attaining economically viable systems that are reliable and maintainable. Because of the high risk associated with this technology development, industry efforts in this area are minimal.

There is a very large potential payoff for laminar flow control, however, and for this reason, substantial resources are included this technology element in the NASA Aircraft Fuel Conservation Technology program.

PROGRAM

The three phases of the Laminar Flow Control program are illustrated in Figure 43, with a schedule of activities given in Figure 44. The first phase will start with the development of materials, structures, and aerodynamics concepts applicable to a practical, reliable, and maintainable system. If early results are encouraging, the program will proceed into system development. Components will be designed, fabricated, and ground tested with emphasis on the reliability and maintainability of the system. If the ground tests are favorable, a flight test demonstration will be undertaken. The flight tests will consist either of a proof-of-concept demonstration of a modified aircraft with laminar flow over major portions of the wing, or an in-service validation of an existing transport aircraft with possibly only a section of the wing treated. Further definition of the most appropriate flight demonstration will be developed as the program proceeds.

The estimated funding required for this program is given by fiscal year and by phases in Figure 45. A total resource commitment of \$100 million is required over the next ten years.

A practical laminar flow control system would be demonstrated through flight tests by 1985 if all phases of this program are successful. This technology could only be incorporated into a completely new-design aircraft. It is estimated that an aircraft using laminar flow control could possibly be introduced into service by 1990.

COMMENTS

In general, the advisors indicated that the potential benefits of laminar flow control are so attractive that the technology should be pursued. Because of the risk factor and long development time, they judged this to be an appropriate activity for NASA. A summary of the advisors' comments is given in Figure 46.

LAMINAR FLOW CONTROL

CONCEPT

**DEVELOP AND DEMONSTRATE A PRACTICAL, RELIABLE,
MAINTAINABLE BOUNDARY-LAYER SUCTION SYSTEM FOR
VISCOUS DRAG REDUCTION**

FUEL SAVINGS

20 – 40% DEPENDING ON RANGE

BASIS FOR TECHNOLOGY READINESS

RESEARCH AIRCRAFT PROOF-OF-CONCEPT FLIGHT TEST

OR

**AIRCRAFT MODIFICATION FOR IN-SERVICE VALIDATION OF
RELIABILITY AND MAINTAINABILITY**

FIGURE 40

LAMINAR FLOW CONTROL FUEL CONSERVATION POTENTIAL

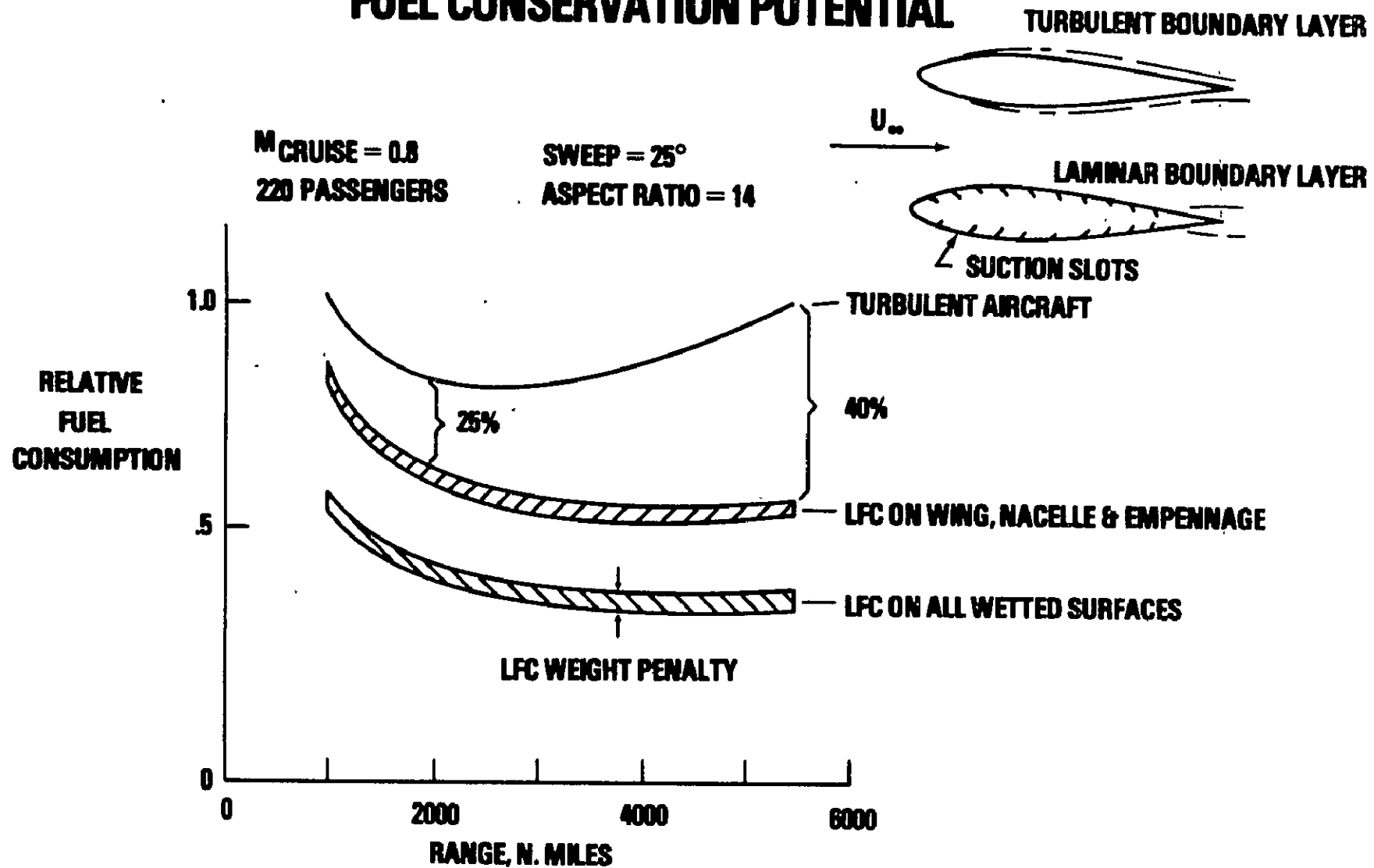


FIGURE 41

X-21 LAMINAR—FLOW—CONTROL AIRCRAFT



UPPER SURFACE



LOWER SURFACE



LAMINAR BOUNDARY LAYER

NON-SUCTION REGIONS

TURBULENT BOUNDARY LAYER IN SUCTION REGIONS

FIGURE 42

LAMINAR FLOW CONTROL

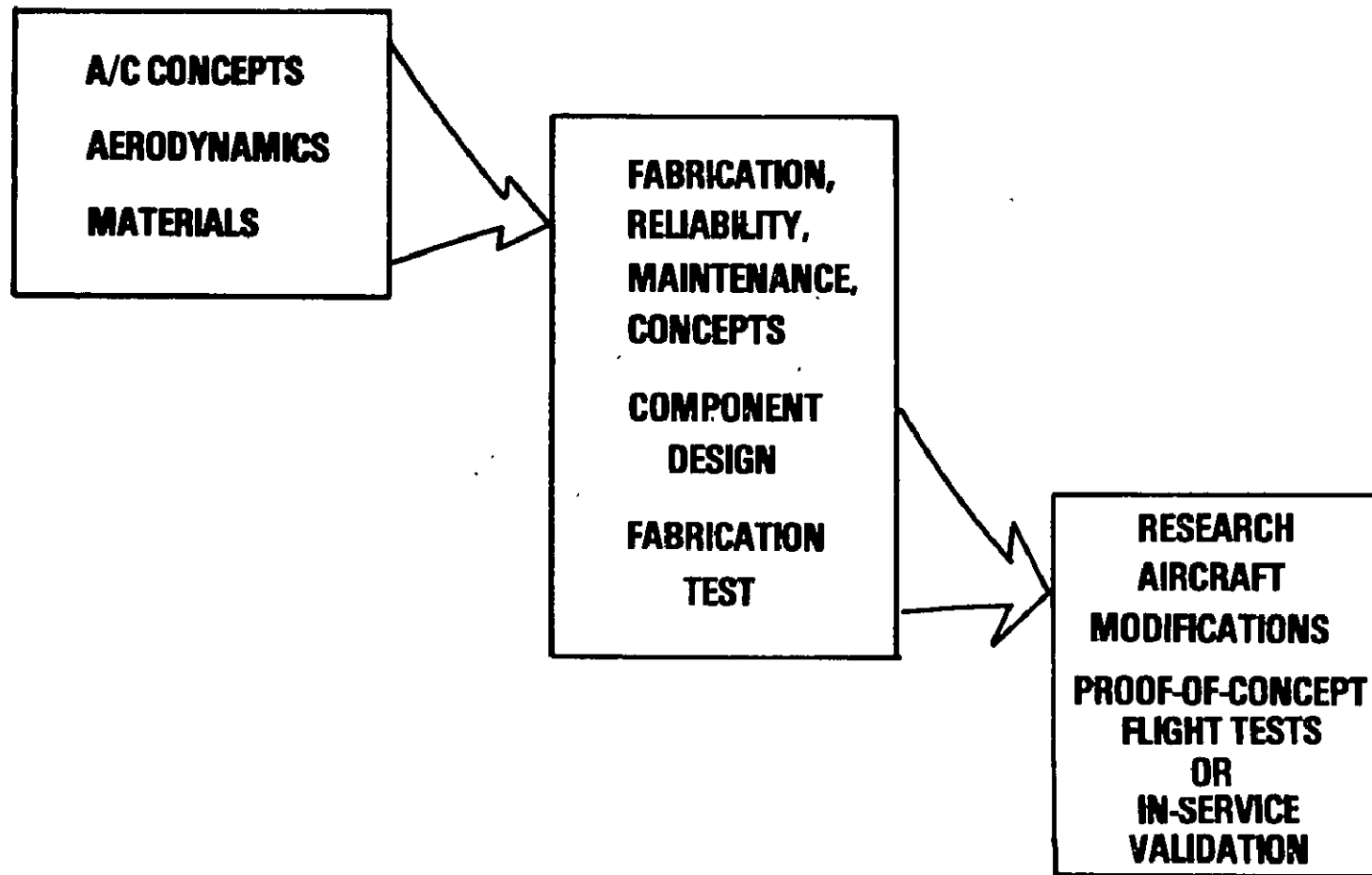


FIGURE 43

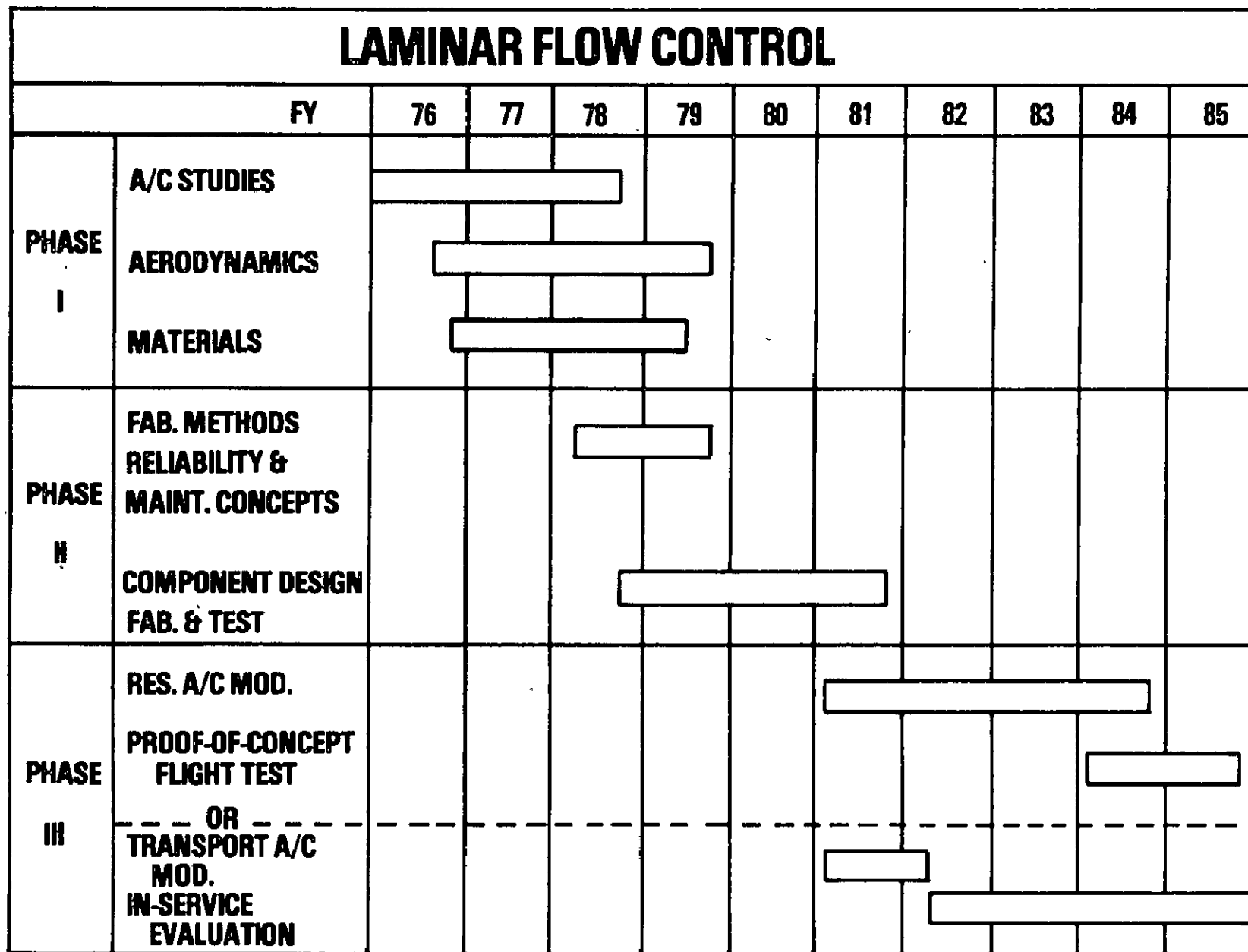
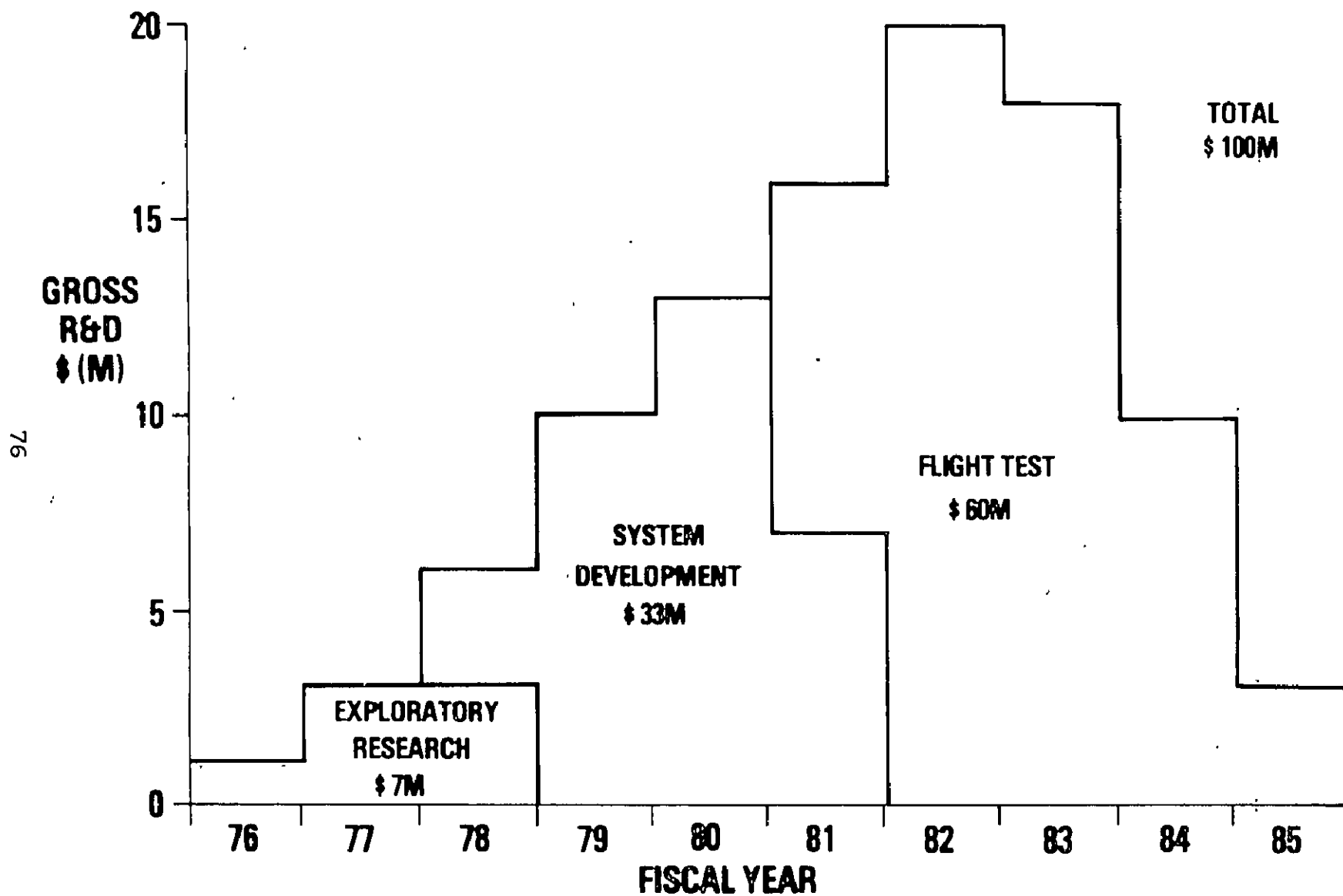


FIGURE 44

LAMINAR FLOW CONTROL



REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

FIGURE 45

LAMINAR FLOW CONTROL

COMMENTS

ADVISORY BOARD

- **EMPHASIS SHOULD BE ON DEVELOPMENT OF PRACTICAL SYSTEM – NASA ENCOURAGED TO PROCEED. FIRST PHASE FUNDING APPROPRIATE.**
- **IN-SERVICE FLIGHT EVALUATION MAY BE REQUIRED TO ANSWER RELIABILITY AND MAINTAINABILITY QUESTIONS.**

ASEB

- **APPROPRIATE RESEARCH ACTIVITY FOR NASA**

STRUCTURES

The development of composite structural materials has proceeded in an orderly manner from laboratory-scale experiments to limited use in military and civil aircraft. Large gains in performance of civil transport aircraft would be available if composite materials were used in primary (flight-critical) structures. The long life-times of civil aircraft require substantial experience with a new material before an aircraft manufacturer will commit to its use. Several years of in-service flight evaluation in realistic environments are required, in the opinion of the manufacturers, before their decision to use composite materials in primary aircraft structures can be made. NASA and the Air Force have complementary programs in the area of composite structures. NASA has assumed responsibility for obtaining the long-term in-service flight evaluation data needed for the design of transport aircraft. NASA has already sponsored extensive in-service evaluation programs on secondary aircraft structures and has initiated work with Lockheed on a composite vertical tail for the L-1011.

The Task Force, at the vigorous urging of the industry advisors, has defined an aggressive Composite Primary Aircraft Structures program that goes considerably beyond the previously planned program. The objective of this program is to greatly accelerate the use of composites in new civil transport aircraft

Composite Primary Aircraft Structures

CONCEPT

- o Accelerate the introduction of composite primary structural components in new aircraft. See Figure 47.

The use of light, high strength-to-weight ratio, fiber-reinforced matrix composite materials shows promise of saving 25 percent in structural weight of future transport aircraft. These composites contain filaments of boron or graphite arrayed in an epoxy, polyimide, or aluminum matrix. A number of composite secondary aircraft structural components, such as spoilers, panels, and rudders, are already in airline service (Figure 48). However, secondary components account for only a fraction of total vehicle weight. A more complete use of composite materials in primary structures is necessary to obtain significant weight and fuel savings. Furthermore, potential significant manufacturing cost savings appear to be available with the use of these materials.

FUEL SAVINGS

- o 10 - 15% compared to all-metal aircraft.

A number of detailed systems and design studies have indicated that the use of composite materials can reduce aircraft structural weight by 25 percent or more and save 10 to 15 percent in fuel usage. Maximum fuel savings can be obtained only through extensive use of composites on all major structural components.

IMPLEMENTATION

NASA, DOD, and the airframe manufacturers are currently engaged in research to develop the technology and confidence needed to exploit composite structures. However, at the current

level of effort, this technology would not be widely used in aircraft structures until well into the 1990's. Extensive service experience is required to enable the airframe industry to commit to the extensive use of composites in new production aircraft. The NASA program is structured to minimize the risks associated with such a commitment by industry. Accordingly, the NASA program was defined with the following objectives:

- o Extensive in-service flight experience
- o Diffusion of technology throughout the transport manufacturing industry
- o Development of design and manufacturing techniques for 3 major components: tail, wing and fuselage
- o Support for industry in development of production processes

PROGRAM

The Composite Primary Aircraft Structures program consists of four elements, as shown in Figure 49. The previously planned NASA program called for in-service evaluation of a composite vertical tail and wing. Completion of the design, fabrication, ground testing and extensive in-service flight evaluations of these two components is included in the expanded program. Additional elements included in the expanded program are: (1) expansion of the vertical tail flight evaluation program, (2) further expansion of the vertical tail program to address the problems associated with the early production phases of composite primary structural parts and (3) design, construction, and in-service evaluation of a composite fuselage. The schedule of activities for these elements is given in Figure 50.

The additional resources required to accomplish these elements are given by fiscal year in Figure 51. The total additional program requirements amount to \$180 million over the next 8 years. The composite fuselage program, with a resource requirement of \$70 million is included as an important, but not first priority element.

The acceleration in the number of composite components and in the number flight-service hours which would be accomplished by this program would permit extensive use of composite primary structures in new aircraft designs initiated in the mid-1980's. It is envisioned that a new aircraft with extensive use of composites could be ready for introduction into service in 1990. Moderate use of composites would be possible on aircraft introduced into service as early as 1985.

COMMENTS

The airframe industry advisors were very strong in their endorsement of this program. They feel confident that this technology will eventually be used and that a vigorous NASA program will give them the required experience and confidence much earlier than would otherwise be the case. They also believe that this technology offers one of the best opportunities for fuel savings. Furthermore, this technology offers the prospect of reduced fabrication costs. It is felt that composites technology may well represent an important part of the competitive advantage of American aircraft industry in the future world market. A summary of advisors' comments is given in Figure 52.

COMPOSITE PRIMARY AIRCRAFT STRUCTURES

CONCEPT

**ACCELERATE THE INTRODUCTION OF COMPOSITE PRIMARY
STRUCTURAL COMPONENTS IN NEW PRODUCTION AIRCRAFT.**

FUEL SAVINGS

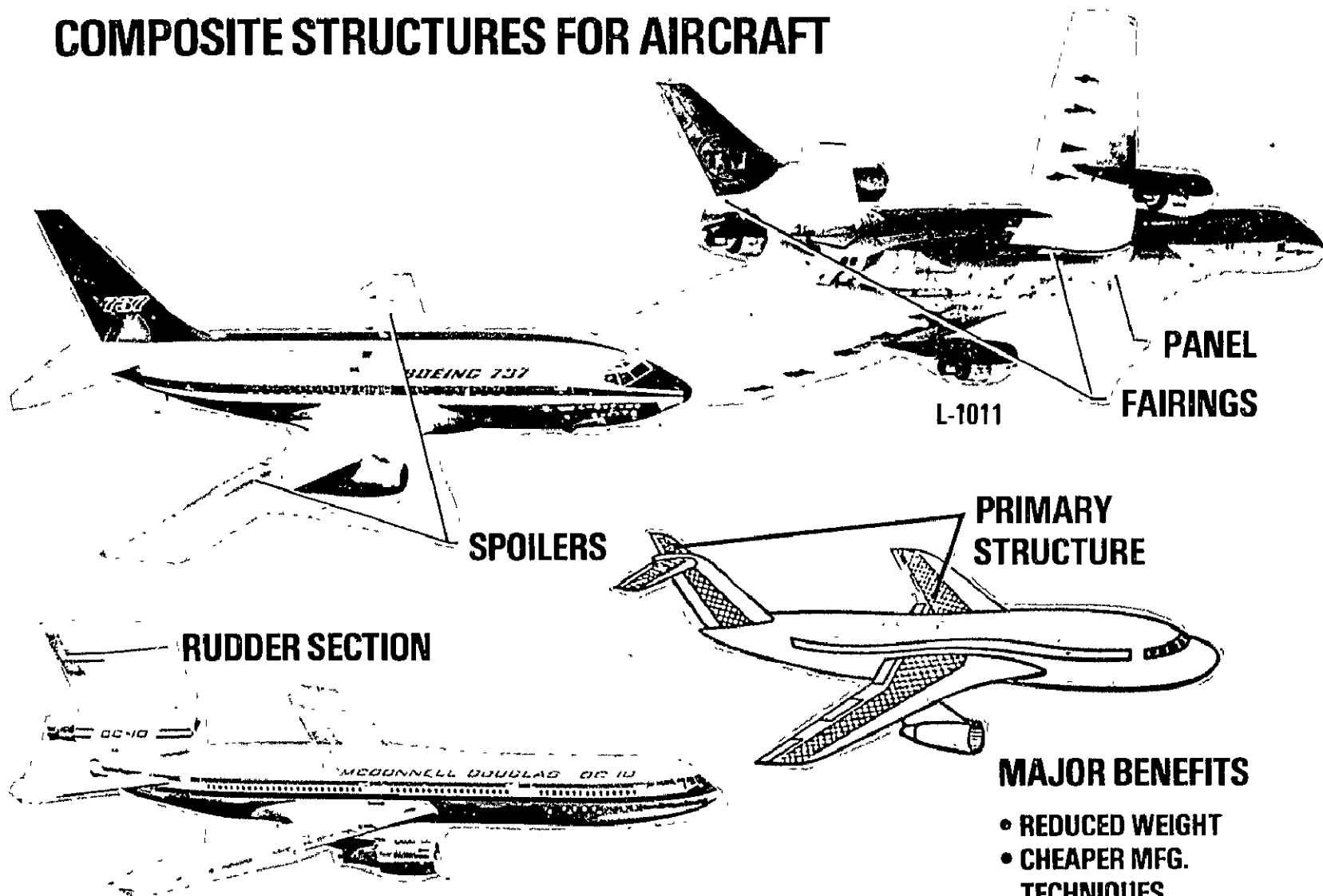
10 – 15% COMPARED TO ALL METAL AIRCRAFT

BASIS FOR TECHNOLOGY READINESS

EXTENSIVE IN-SERVICE EXPERIENCE

FIGURE 47

COMPOSITE STRUCTURES FOR AIRCRAFT



MAJOR BENEFITS

- REDUCED WEIGHT
- CHEAPER MFG. TECHNIQUES
- REDUCED MAINTENANCE
- LONGER FATIGUE LIFE

FIGURE 48

COMPOSITE PRIMARY AIRCRAFT STRUCTURES

PROGRAM ELEMENTS:

- IN SERVICE EXPERIENCE OF COMPOSITE VERTICAL TAIL AND WING (PREVIOUSLY PLANNED NASA PROGRAM)
- EXPANSION OF VERTICAL TAIL PROGRAM TO INCLUDE THREE MAJOR AIRFRAME MANUFACTURERS
- EXTENSION OF THE VERTICAL TAIL PROGRAM TO SUPPORT THE EARLY PRODUCTION PHASE
- CONSTRUCTION AND IN SERVICE EXPERIENCE OF A COMPOSITE FUSELAGE

FIGURE 49

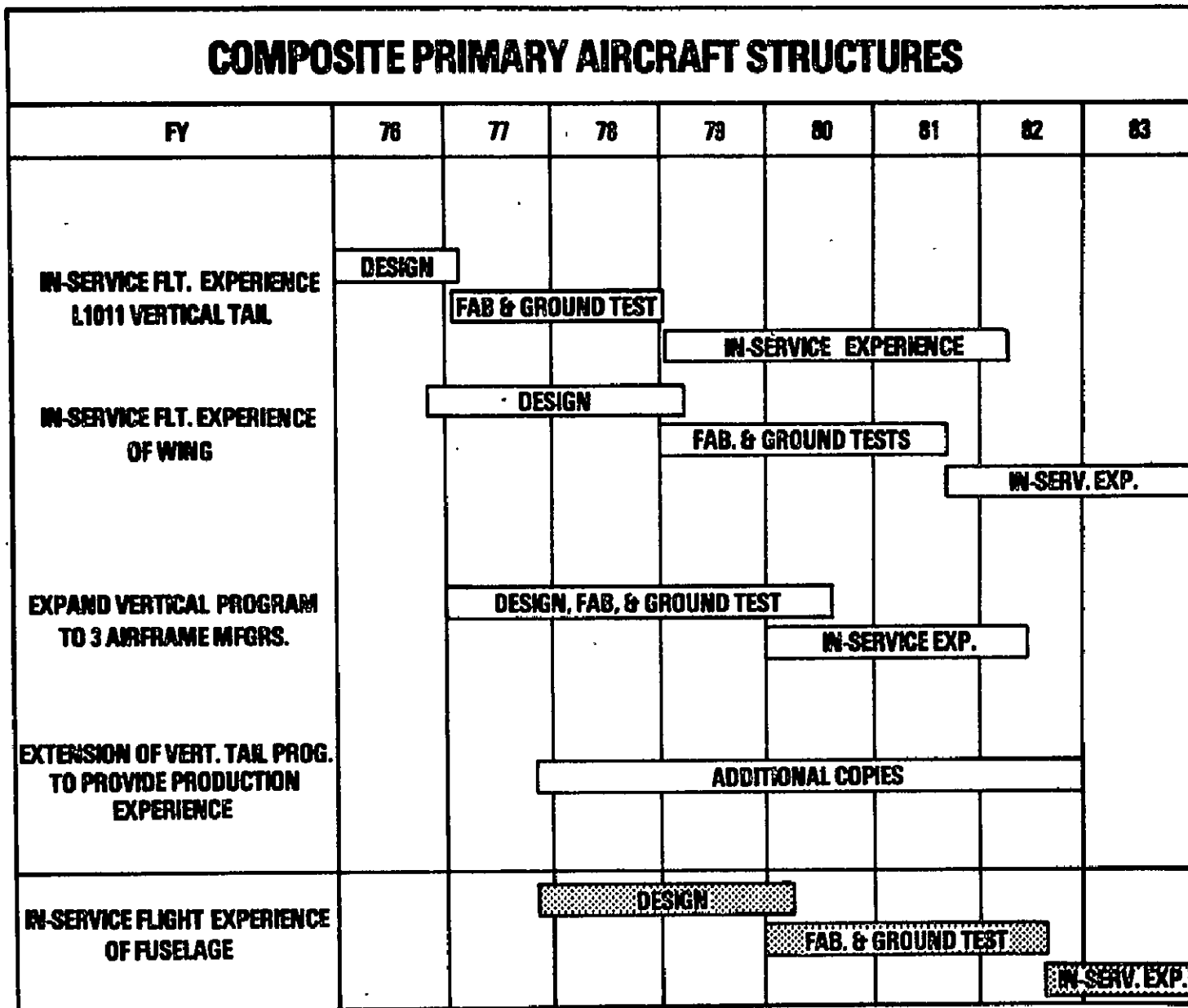


FIGURE 50

COMPOSITE PRIMARY AIRCRAFT STRUCTURES

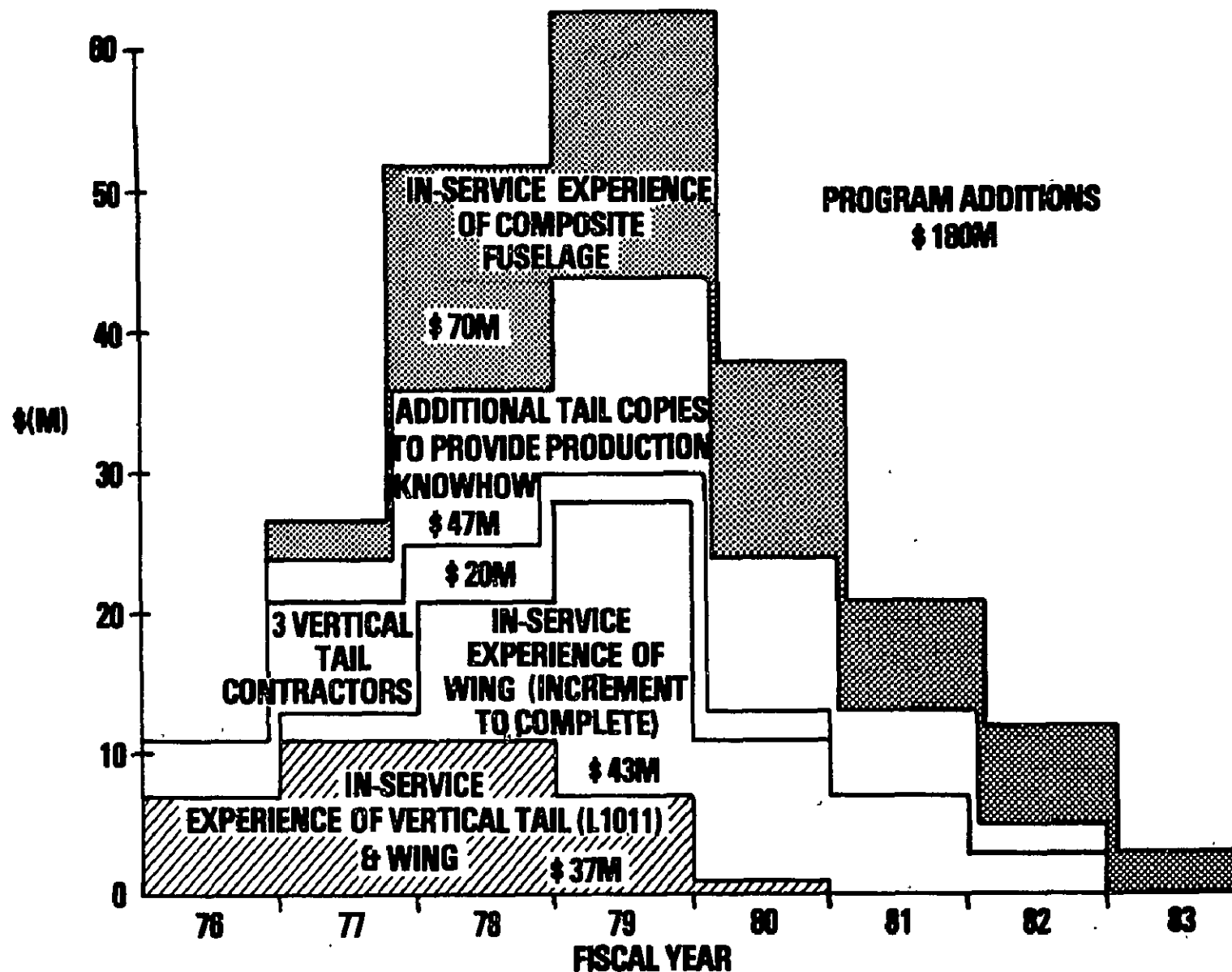


FIGURE 51

COMPOSITE PRIMARY AIRCRAFT STRUCTURES

COMMENTS

ADVISORY BOARD

- **STRONG ENDORSEMENT FOR VERTICAL TAIL AND WING IN-SERVICE EXPERIENCE PROGRAM**
- **INCLUDE IN-SERVICE EXPERIENCE OF FUSELAGE**
- **NASA SHOULD ALSO RECOGNIZE COST SAVING POTENTIAL OF COMPOSITES**

ASEB

- **COMPOSITES IS MAJOR PAYOFF AREA**
- **NASA PROGRAM TOO SMALL**
 - **FLIGHT DEMONSTRATION TOO FAR DOWNSTREAM**
 - **ACCELERATE AT EXPENSE OF ALMOST ANYTHING ELSE**
- **GO WITH USAF TO GET EARLY RESULTS**

FIGURE 52

ADDITIONAL TECHNOLOGIES NOT INCLUDED

The Task Force did not consider technology to develop alternate fuel sources nor the technology to use alternate fuels in aircraft. It was assumed that portable fuels, whether natural petroleum or some substitute, would be expensive and in short supply and that the need for conservation would be urgent.

The Task Force considered a broad range of possible technological development activities that might result in fuel conservation in addition to those for which development programs have been defined. Several items for which specific programs were not recommended are summarized in Table 5. The first two items were discussed previously. The third item, Compliant Walls and Slot Injection, was judged not ready for intensified development at this time. The work done to date on compliant walls does appear, however, to offer considerable promise for drag reduction through a favorable interaction between the turbulent pressure fluctuations in the boundary layer and a resilient or compliant coating on the wetted surface of an aircraft.

NASA is engaged in research on several special-purpose vehicles. However, it does not appear that any unconventional aircraft configurations will be present in sufficient numbers in this century to warrant special attention from a fuel conservation standpoint.

The Task Force searched for a technology development opportunity in operations or avionics. The hope was to permit more efficient operation of existing aircraft. However, the conclusion reached after extensive consideration was that no further improvements in on-board equipment were appropriate within the confines of the existing air traffic control systems. The airlines were confident that the FAA recognized this situation and was moving aggressively to improve the system. NASA is prepared to assist the FAA if any technology development tasks are to be delegated to it by the FAA in this area.

Expansion of the Terminal Configured Vehicle program (TCV) was considered not appropriate at this time. It is expected that new areas of effort will be identified as the currently planned program proceeds. Possible expansions of the TCV program will be considered at appropriate times in the future.

Improvements in secondary systems such as cabin air conditioning or the use of powered wheels for ground movement of aircraft are interesting concepts but do not result in sufficient fuel savings to justify a focussed effort as part of the Task Force's recommended program.

TECHNOLOGY ELEMENTS NOT INCLUDED IN AFCT

<u>ITEM</u>	<u>CONCEPT</u>	<u>CRITICAL CONSIDERATIONS</u>
TEN-TON ENGINE	RETROFIT HIGH-BYPASS-RATIO ENGINES ON NARROW-BODY AIRCRAFT TO SAVE 15% FUEL.	IMPLEMENTATION BLOCKED BY CAPITAL REQUIREMENTS. NO TECHNOLOGY TASK IDENTIFIED FOR NASA.
REVISED ENGINE MAINTENANCE PROCEDURES	IMPROVE STRATEGY ON PART REPLACEMENT TO RESULT IN LOWER FUEL CONSUMPTION.	AIRLINES FEEL THAT OPTIMUM BALANCE BETWEEN FUEL AND PARTS COST EXIST NOW.
COMPLIANT WALLS AND SLOT INJECTION	FRICTION DRAG REDUCTION	NOT READY FOR LARGE-SCALE DEVELOPMENT EFFORT.
UNCONVENTIONAL CONFIGURATIONS TILT ROTOR AIRCRAFT OBLIQUE WING AIRCRAFT SPANLOADED AIRCRAFT	SPECIAL PURPOSE AIRCRAFT IN VARIOUS STAGES OF DEVELOPMENT	NO WIDESPREAD USE AS CIVIL TRANSPORTS SEEN IN NEAR FUTURE.
OPERATIONS/AVIONICS	MORE EFFICIENT OPERATION OF EXISTING AIRCRAFT.	ATC SYSTEM IS LIMITING FACTOR. NO TECHNOLOGY DEVELOPMENT TASK FOR NASA. MAINTAIN CONTACT WITH FAA ON THIS ISSUE.
TCV PROGRAM EXPANSION	DEVELOP AND CERTIFY FLIGHT-READY AVIONICS	NASA SUPPORT NOT REQUIRED NOW.
SECONDARY SYSTEMS	MORE EFFICIENT CABIN AIR CONDITIONING AND AIRCRAFT GROUND PROPULSION	SMALL GAINS DO NOT WARRANT NASA ACTION.

TABLE 5

RESOURCES

As described, each of the six technology elements was structured in phases. Funding requirements by fiscal year were estimated for each phase of every element and are presented in Table 6. This funding distribution is illustrated for each of the technology elements in Figure 53. The total cost over the ten-year period (1976 - 1985) of all the elements discussed is \$670 million. If those elements of lower priority which were judged highly promising (the Level II activities shown shaded in Figure 53) are not included, the total cost of the baseline program is \$490 million. These costs are based on the assumption that all phases of the technology elements are pursued to completion. As discussed, a decision to proceed is made at the completion of each phase. A matrix of decision points for each technology element is given in Figure 54.

The near-term (FY 76 - 78) funding requirements for the total program and the baseline program are given in Tables 7 and 8. The total amounts required in the three-year period are \$142 million and \$104 million for the total and baseline programs respectively. The funding split by phases for both program levels is plotted in Figures 55 and 56. The Phase I effort is \$195 million in the case of both the total and baseline programs. The peak funding year is FY 1979 at \$150 million for the total program and FY 1980 at \$109 million for the baseline program. Assuming that the program additions proposed herein are supported, the FY 76 - FY 78 distribution by propulsion, aerodynamics, and structures of NASA's overall efforts on aircraft fuel conservation technology, including the on-going programs, is given in Table 9. The funding distribution by discipline area would be approximately 40% for both propulsion and structures, and 20% for aerodynamics during the next three years.

NASA's current commitment to the technology for aircraft fuel conservation is substantial. The proposed program additions are being evaluated to determine how and to what extent the initial phases of the program can be supported. Subsequent fiscal year funding requirements will be considered as part of the agency budget preparation and will be determined in the budget development process.

SUMMARY OF TASK FORCE RECOMMENDATIONS

R&D \$ IN MILLIONS

Fiscal Year	'76	'76TP	'77	'78	'79	'80	'81	'82	'83	'84	'85	Totals
<u>BASELINE PROGRAM</u>												
<u>Engine Component Improvement</u>	<u>1.5</u>	<u>0.5</u>	<u>9.0</u>	<u>10.0</u>	<u>12.0</u>	<u>7.0</u>	-	-	-	-	-	<u>40.0</u>
<u>Fuel Conservative Engines</u>	<u>1.5</u>	<u>0.5</u>	<u>6.0</u>	<u>12.0</u>	<u>30.0</u>	<u>35.0</u>	<u>20.0</u>	<u>10.0</u>	-	-	-	<u>115.0</u>
I Component Development	1.5	0.5	6.0	7.0								15.0
II Engine Component Development				5.0	30.0	25.0						60.0
III Experimental Engine						10.0	20.0	10.0				40.0
<u>Turboprops</u>	<u>1.4</u>	<u>0.6</u>	<u>3.0</u>	<u>6.0</u>	<u>11.0</u>	<u>20.0</u>	<u>26.0</u>	<u>7.0</u>	-	-	-	<u>75.0</u>
I Prop. Aerodynamics	1.4	0.6	3.0	3.0								8.0
II Prop. Structures - Gears				3.0	6.0	8.0						17.0
III Engine Demonstration					5.0	12.0	26.0	7.0				50.0
<u>Fuel Conservative Transport</u>	<u>1.5</u>	<u>0.5</u>	<u>4.0</u>	<u>8.0</u>	<u>11.0</u>	<u>11.0</u>	<u>10.0</u>	<u>4.0</u>	-	-	-	<u>50.0</u>
I Aerodynamic Development	1.5	0.5	4.0	5.0	4.0							15.0
II Transport Design Validation				2.0	5.0	3.0						10.0
III Technology Flight Demonstration				1.0	2.0	8.0	10.0	4.0				25.0
<u>Laminar Flow Control</u>	<u>0.8</u>	<u>0.2</u>	<u>3.0</u>	<u>6.0</u>	<u>10.0</u>	<u>13.0</u>	<u>16.0</u>	<u>20.0</u>	<u>18.0</u>	<u>10.0</u>	<u>3.0</u>	<u>100.0</u>
I Concept Development	0.8	0.2	3.0	3.0								7.0
II System Development				3.0	10.0	13.0	7.0					33.0
III System Flight Demonstration							9.0	20.0	18.0	10.0	3.0	60.0
<u>Composite Primary Structures</u>	<u>0.5</u>	<u>0.5</u>	<u>16.0</u>	<u>25.0</u>	<u>27.0</u>	<u>23.0</u>	<u>13.0</u>	<u>5.0</u>	-	-	-	<u>110.0</u>
<u>TOTAL BASELINE PROGRAM</u>	<u>7.2</u>	<u>2.8</u>	<u>41.0</u>	<u>67.0</u>	<u>101.0</u>	<u>109.0</u>	<u>85.0</u>	<u>46.0</u>	<u>18.0</u>	<u>10.0</u>	<u>3.0</u>	<u>490.0</u>
<u>LEVEL II PROGRAM</u>												
Fuel Conservative Engine, Additional Component Development	-	-	-	5.0	30.0	25.0	-	-	-	-	-	60.0
Turboprop Flight Test	-	-	-	-	-	-	5.0	20.0	20.0	5.0	-	50.0
Composite Fuselage	-	-	3.0	16.0	19.0	14.0	8.0	7.0	3.0	-	-	70.0
<u>TOTAL LEVEL II PROGRAM</u>	<u>-</u>	<u>-</u>	<u>3.0</u>	<u>21.0</u>	<u>49.0</u>	<u>39.0</u>	<u>13.0</u>	<u>27.0</u>	<u>23.0</u>	<u>5.0</u>	<u>-</u>	<u>180.0</u>
<u>TOTAL PROGRAM</u>	<u>7.2</u>	<u>2.8</u>	<u>44.0</u>	<u>88.0</u>	<u>150.0</u>	<u>148.0</u>	<u>98.0</u>	<u>73.0</u>	<u>41.0</u>	<u>15.0</u>	<u>3.0</u>	<u>670.0</u>

TABLE 6

TOTAL PROGRAM — ADDITIONAL RESOURCE REQUIREMENTS

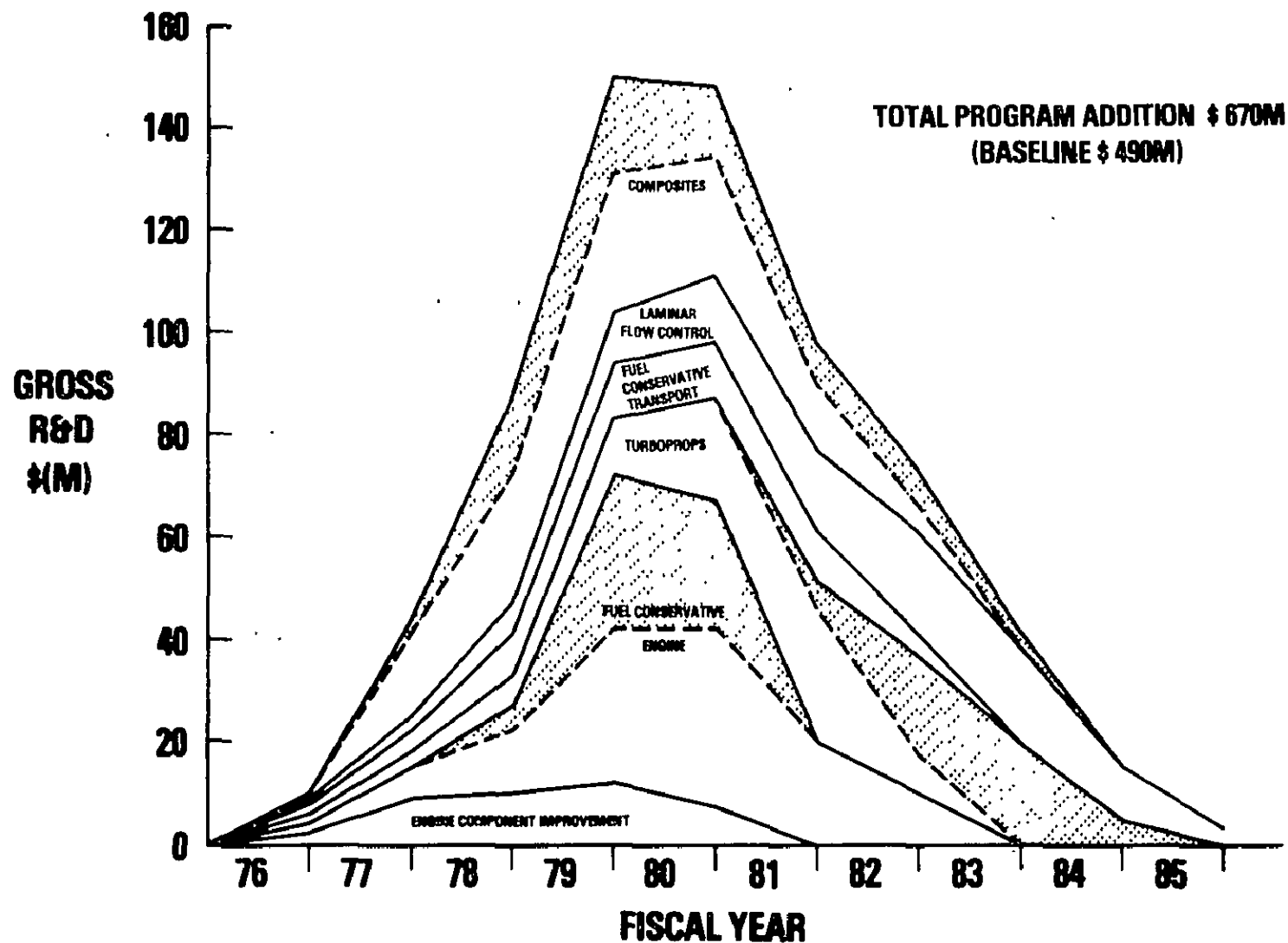
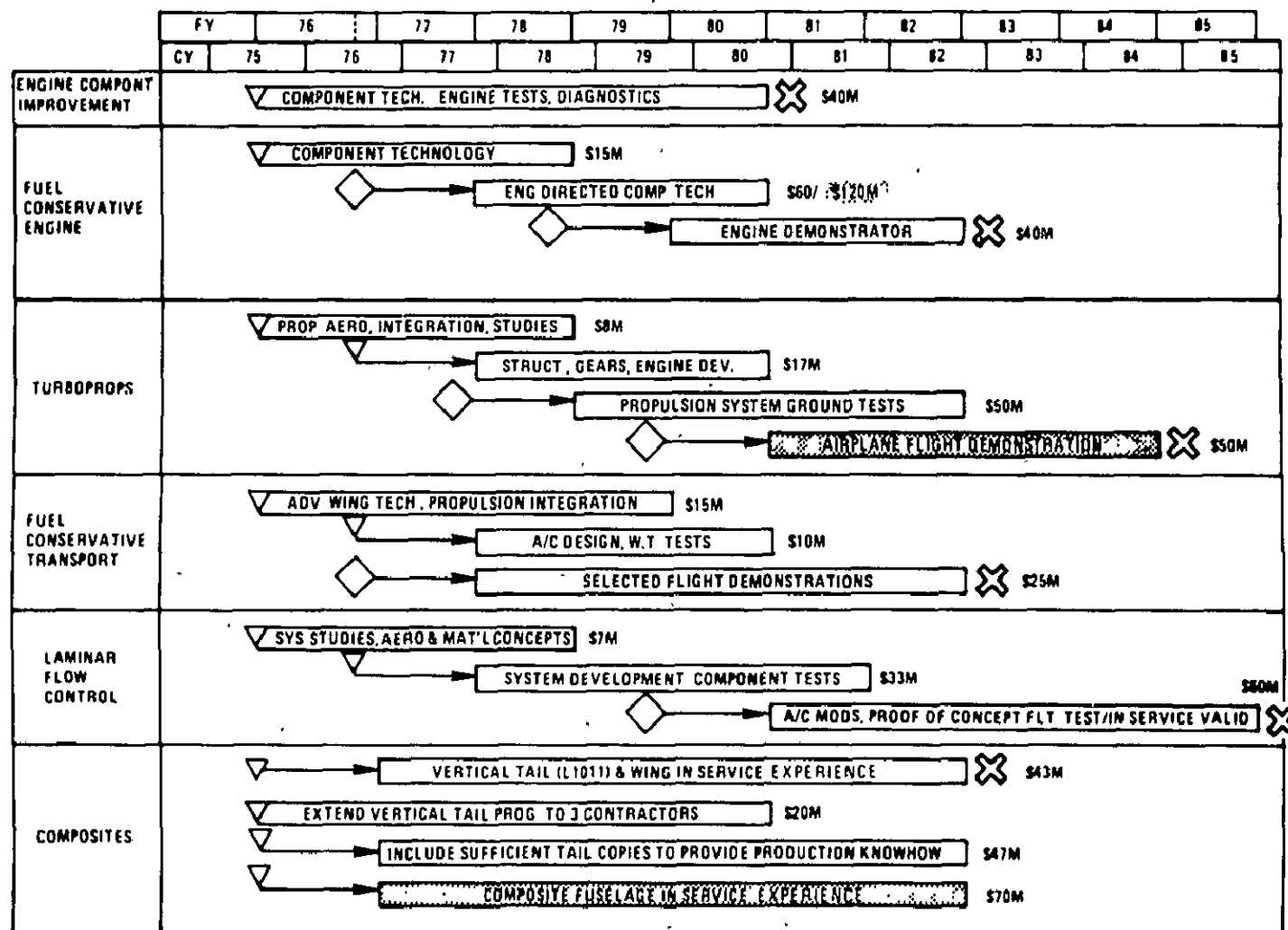


FIGURE 53

DECISION POINT FLOW CHART



SYS TECH NEW START

EXPR PROG NEW START

TECHNOLOGY READINESS

FIGURE 54

NEAR-TERM FUNDING REQUIREMENTS — TOTAL PROGRAM ADDITION \$ MILLIONS

	FY 76	FY 77	FY 78	3-YR TOTAL
ENGINE COMPONENT IMPROVEMENT	2.0	9.0	10.0	21.0
FUEL CONSERVATIVE ENGINE	2.0	6.0	17.0	25.0
TURBOPROPS	2.0	3.0	6.0	11.0
FUEL CONSERVATIVE TRANSPORT	2.0	4.0	8.0	14.0
LAMINAR FLOW CONTROL	1.0	3.0	6.0	10.0
COMPOSITES	1.0	19.0	41.0	61.0
TOTALS	10.0	44.0	88.0	142.0

TABLE 7

**NEAR-TERM FUNDING REQUIREMENTS —
BASELINE PROGRAM ADDITION PHASE I
\$ MILLIONS.**

	FY 76	FY 77	FY 78	3-YR TOTAL
ENGINE COMPONENT IMPROVEMENT	2.0	9.0	10.0	21.0
FUEL CONSERVATIVE ENGINE	2.0	6.0	7.0	15.0
TURBOPROPS	2.0	3.0	3.0	8.0
FUEL CONSERVATIVE TRANSPORT	2.0	4.0	5.0	11.0
LAMINAR FLOW CONTROL	1.0	3.0	3.0	7.0
COMPOSITES	1.0	16.0	25.0	42.0
TOTALS	10.0	41.0	53.0	104.0

TABLE 8

97

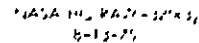


FIGURE 55

FUNDING BY PHASES — BASELINE PROGRAM ADDITION

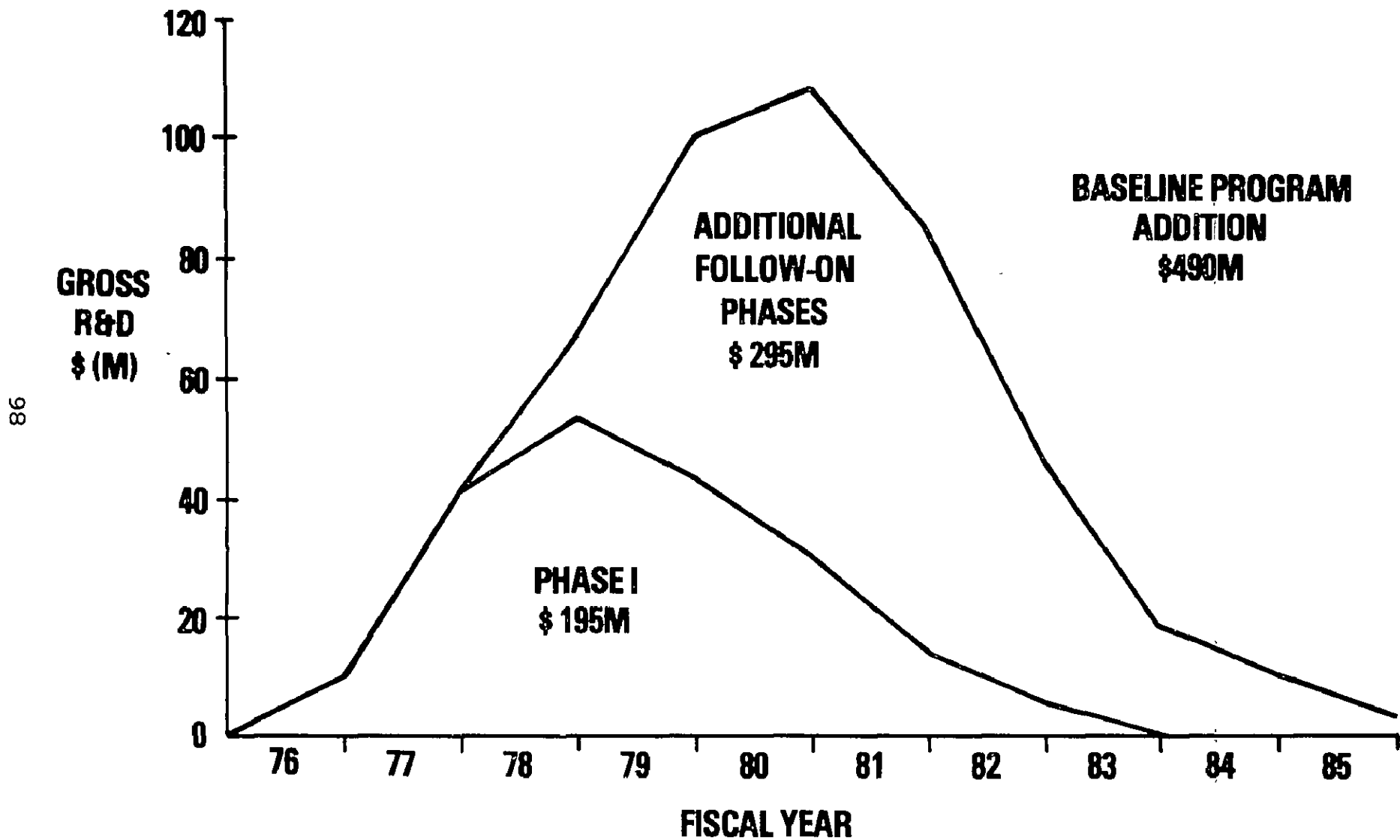


FIGURE 56

NEAR TERM FUNDING REQUIREMENTS — TOTAL PROGRAM (FY 76-78)

\$ MILLIONS

		ON-GOING	ADDITIONS	TOTAL	% OF TOTAL
PROPULSION —	ENGINE COMPONENT IMPROVEMENT	1.5	21.0	22.5	90.5
	FUEL CONSERVATIVE ENGINE	32.0	25.0	57.0	
	TURBOPROPS	0	11.0	11.0	
AERODYNAMICS —	FUEL CONSERVATIVE TRANSPORT	20.0	14.0	34.0	44.0
	LAMINAR FLOW CONTROL	0	10.0	10.0	
STRUCTURES —	COMPOSITES	29.0	61.0	90.0 — 90.0	40
		82.5	142.0	224.5	100

TABLE 9

BENEFITS

The potential fuel savings associated with the different technology elements have been presented along with a description of the technical activity. In this section, an attempt is made to determine how these technologies would combine in any single aircraft design and to estimate the fuel savings that could result as these new aircraft are introduced into the domestic fleet.

It is of course not possible to make a fuel savings estimate with any precision. Each newly-designed aircraft incorporates a number of technology advances and is the result of a careful and detailed optimization process which considers many factors, such as range, passenger-carrying capacity, utilization rate, initial cost, etc. Achievement of the fuel conservation benefits estimated here is dependent on successful technological development. Such success is dependent not only on the application of adequate resources but also on a certain amount of good fortune. Realization of fuel savings comes about primarily by the introduction of technology developments into new products. Demand for travel brings about the demand for new aircraft, and the development of these new aircraft depends on industry capability to meet capital requirements. In short, the link between promising technological elements and realized fuel savings is a long and complex one.

FLEET MODEL

To predict the possible benefits from this program, the total revenue passenger miles (RPM) were projected from 1975 to 2005 using a constant growth rate of 4% per year. As shown in Figure 57, except for 1974 this assumed growth rate is considerably lower than that experienced in the past and reflects the fact that the air transportation industry is becoming a mature industry. Future traffic growth is therefore expected to be more closely related to real growth in GNP over the next 30 years. The 4% growth rate is a conservative estimate and probably represents a lower bound on airline traffic growth during this time period.

The aircraft comprising the existing commercial airline fleet were grouped into four

aircraft categories. Based on the number of existing aircraft, the average capacity, block speed, utilization rate and fuel consumption, and using an assumed load factor of 55%, an average fuel utilization was calculated. These results, in fuel use per RPM by aircraft category, are shown in Table 10.

In the fleet model that was assumed, total revenue passenger miles were allocated to the aircraft types grouped in three classes according to their range capability:

Short Range Capability:	12% RPM
Medium Range Capability:	42% RPM
Long Range Capability:	46% RPM

These percentages were projected to remain constant over the 30-year period, so that each segment of the existing market is assumed to increase at the constant 4% growth rate. The four aircraft categories were assigned to the different range capability classes, with the four-engine narrow-body aircraft divided equally between the long-range and medium-range classes according to current distribution of use.

The existing commercial fleet was projected into the future assuming a useful life of 15 years for each aircraft type. Fleet inventory data for the years 1961 - 1974 were examined to determine when each existing aircraft type would be retired from service. The deficit in RPM was then filled by new production aircraft with the same range capability as the aircraft which were replaced. All newly-produced aircraft were also assumed to have a 15-year lifetime.

The resulting projected U. S. airline fleet distribution is shown in Figure 58. All aircraft in service during 1975 are retired by 1990. Continued production of current technology aircraft is assumed in each case for a certain number of years, after which that aircraft type is replaced by either a derivative or a new design aircraft. This

projection was then used to estimate future airline fuel consumption.

BASELINE FUEL CONSUMPTION

In estimating the benefits associated with the NASA technology program, it is first necessary to identify the gains that are currently available and that would be realized without benefit of a government-sponsored program. To perform this calculation, the following assumptions were made:

In 1978, a derivative medium-range aircraft could be introduced into service to replace the current fleet of 3-engine narrow-body aircraft. This new aircraft could be the refanned B-727-300, or somewhat later, an aircraft using the high-bypass-ratio GE/Snecma CFM56 or the P&W JT10D engines, or possibly a derivative twin-engine wide-body. This new aircraft is estimated to have a 15% improvement in SFC over the current B-727 fleet to provide an average fuel use of 1.251 bbl per thousand RPM.

In 1983, a derivative long-range aircraft could be introduced into service. This aircraft could be a stretched version of the current B-747, DC-10 or L-1011. The improvement in fuel consumption as compared to the existing wide-body aircraft is estimated at 10%, to give an average fuel use of .892 bbl per thousand RPM.

In 1988, at the projected growth rate, the short-range market might justify the introduction of a new aircraft to satisfy the demand. This aircraft would probably not be very different from the existing DC-9's or B-737's because of the special requirements of the short-haul market, particularly in terms of average stage length, traffic density and number of competitors. This aircraft is assumed to be 10% more efficient than the current two-engine narrow-body aircraft to provide an average fuel consumption of 1.330 bbl per thousand RPM.

Using the assumptions outlined above, the baseline fuel consumption for the next 30 years can be estimated. These results are illustrated in Figure 59. The total consumption over the 30-year period would be just under 13 billion barrels, with 675 million barrels a year (1.85 million barrels a day) consumed by the domestic air transportation industry in the year 2005. The total revenue passenger miles would have increased by a factor of 3.2 and the fuel use by a factor of 2.8. By the year 2000, the fleet as a whole, based only on existing technology and the replacement of the older four-engine narrow-body aircraft, could be approximately 17% more efficient than the current fleet.

POTENTIAL FUEL SAVINGS

Assuming that the proposed technology program is successful, it is necessary to allow adequate time for design, development, certification and production before a new engine or aircraft can be introduced into service. The application of each technology element must be determined and an estimate made of the introduction date and the fuel savings which result from the combination of these technologies. NASA is continuing to develop a model of the future air transport fleet and methods to assess the impact of advanced technology. As a first step, a preliminary estimate was made of the timing for the introduction of new technology and the potential fuel savings which could result. These assumptions are illustrated in Figure 60 and described below.

Continued Production Aircraft

The results of the Engine Component Improvement program could be available in 1980 and could be used on new production of existing engine types shortly thereafter. An improvement of 5% in SFC for all twin-engine narrow-body aircraft introduced into service after 1982 could result from implementation of this technology.

Derivative Aircraft

The derivative three-engine narrow-body aircraft produced after 1982 could also benefit from the Engine Component Improvement program and could be an additional 5% more efficient than aircraft that would have been produced without this technology. This could result in the derivative medium-range aircraft, introduced into service after 1982, which would have a 20% improvement in fuel consumption as compared with current three-engine narrow-body aircraft.

The derivative three- or four-engine wide-body aircraft introduced in 1983 could benefit from both the Engine Component Improvement program and from the Fuel Conservative Transport program. This aircraft could have reduced static stability for lower trim drag and an improved wing in addition to a more efficient engine. These two technologies could result in an additional 10% improvement over the aircraft that would have otherwise been produced, or a 20% improvement in fuel use as compared to the current wide-body aircraft.

New Design Aircraft

A new medium-range aircraft could be introduced in 1985 which would incorporate some aerodynamic improvements and would benefit from the use of composites in the vertical tail and in secondary structures such as the floorbeams, elevons, slats, etc. An estimated 5% fuel savings could result from these technologies, so that the new aircraft could be an additional 5% more efficient than the 1982 derivative aircraft, and provide a 25% improvement in fuel use as compared with current aircraft.

By 1988, when a new narrow-body short-range aircraft is assumed to be introduced, it might be possible to make extensive use of composites for the primary structures and to incorporate substantial aerodynamic improvements in the aircraft design. Assuming that a reliable turboprop engine has been demonstrated, this new short-haul aircraft could be a

candidate for that propulsion system. The combination of all these technology elements could result in a new aircraft that is 30% more efficient than the 1982 continued-production aircraft, or 35% improved when compared to the twin-engine narrow-body aircraft in the current fleet.

If the proposed technology development program is successful, available improvements in SFC might warrant the introduction of two additional aircraft into service before the end of the century. The first of these, a new long-range wide-body aircraft, could be introduced in 1990 and could provide an additional 30% improvement in fuel use as compared to the derivative wide-body aircraft, or 50% as compared to the existing B-747's, DC-10's and L-1011's. This new aircraft could have an improved engine, composite primary structures, active controls, optimized aerodynamic design, and could also have a laminar flow control system, provided the development of this technology element is successful.

The second aircraft which could be introduced in the 1990's would be a new medium-range transport that could come into service in 1995. This aircraft could incorporate many of the improvements that were applied to the 1990 wide-body aircraft. A turboprop propulsion system might also prove to be very attractive for an aircraft of this size and design range. This new aircraft could be an additional 25% more efficient than the new medium-range aircraft introduced in 1985, ten years earlier, and could provide an overall improvement in fuel use of 50% as compared to the existing B-727's. The forecast distribution of fuel use, based on the assumption described above, is shown in Figure 61.

FUEL SAVINGS

The potential U.S. airline fuel use is summarized in Figure 61. The top line is an estimate of the fuel that would be used if no technology advances were incorporated into the fleet and

only the older four-engine narrow-body jets are retired from service. With no technology improvements, the projected fuel consumption of the U.S. fleet would be 769 million barrels a year (2.1 million barrels a day) by the year 2005. The second line is the estimate of the fuel that would be used if all currently-available technology gains were incorporated into new or derivative aircraft as they were introduced into service. The fuel savings that could be realized amounts to nearly 95 million barrels a year in 2005, or 1.24 billion barrels integrated over the 25-year period from 1980 to 2005.

The lower line gives the estimated fuel use that could result if the derivative and new aircraft that are assumed to be introduced into the fleet incorporate the technology advances described in this report. The fleet fuel consumption in the year 2005 would be 430 million barrels a year (1.18 million barrels a day) as compared to the baseline projection of 675 million/year (1.85 million/day).

The comparison between these two projections is shown again in a different form in Figure 62. The cumulative U.S. airline fuel savings could total approximately 2 billion barrels during the 25-year period from 1980 to 2005. At a constant price of 30¢/gallon, this amounts to \$25 billion saved in fuel costs. The savings in the year 2005 could be 245 million barrels a year, or 670,000 barrels a day. If the rate of air traffic growth is higher than that assumed - 5.4% rather than 4.0% - then the fuel savings would be one million barrels per day in 2005. Based on the assumptions used, the average fleet efficiency could be approximately .7 barrels/1000 RPM or 34 passenger miles per gallon. The most efficient aircraft, the new long-range transport introduced in 1990, could have a fuel use of approximately .5 barrels/1000 RPM, or 48 passenger miles per gallon.

SUMMARY

It does appear that the efforts of industry combined with a vigorous government-sponsored research program could result in a reduction of from 40 to 50 percent in the amount of fuel required per unit of passenger travel. Achievement of this goal is dependent on many factors - successful technological development, market demand for new aircraft, capitalization of the development and production cost of new aircraft, etc.

These factors are well beyond the control of any one group and cannot be predicted with any certainty. The Task Force program plan has attempted to identify technology elements with a reasonable chance of successful development and a good chance of implementation. The application of these advanced technologies to a new generation of fuel-efficient transports is expected to have a significant favorable impact on the fuel consumption of the commercial airline fleet.

In addition to the benefits of reduced fuel consumption, there are other significant benefits which cannot be readily quantified. Among these are:

- Investment in U.S. technology development rather than purchase of foreign oil.

- Continuation of the availability of air travel at reasonable cost to the public.

- Continuation of U.S. dominance of the world transport aircraft market by maintaining a superior technological position.

ANNUAL GROWTH RATES OF U.S. SCHEDULED CERTIFICATED AIR CARRIERS

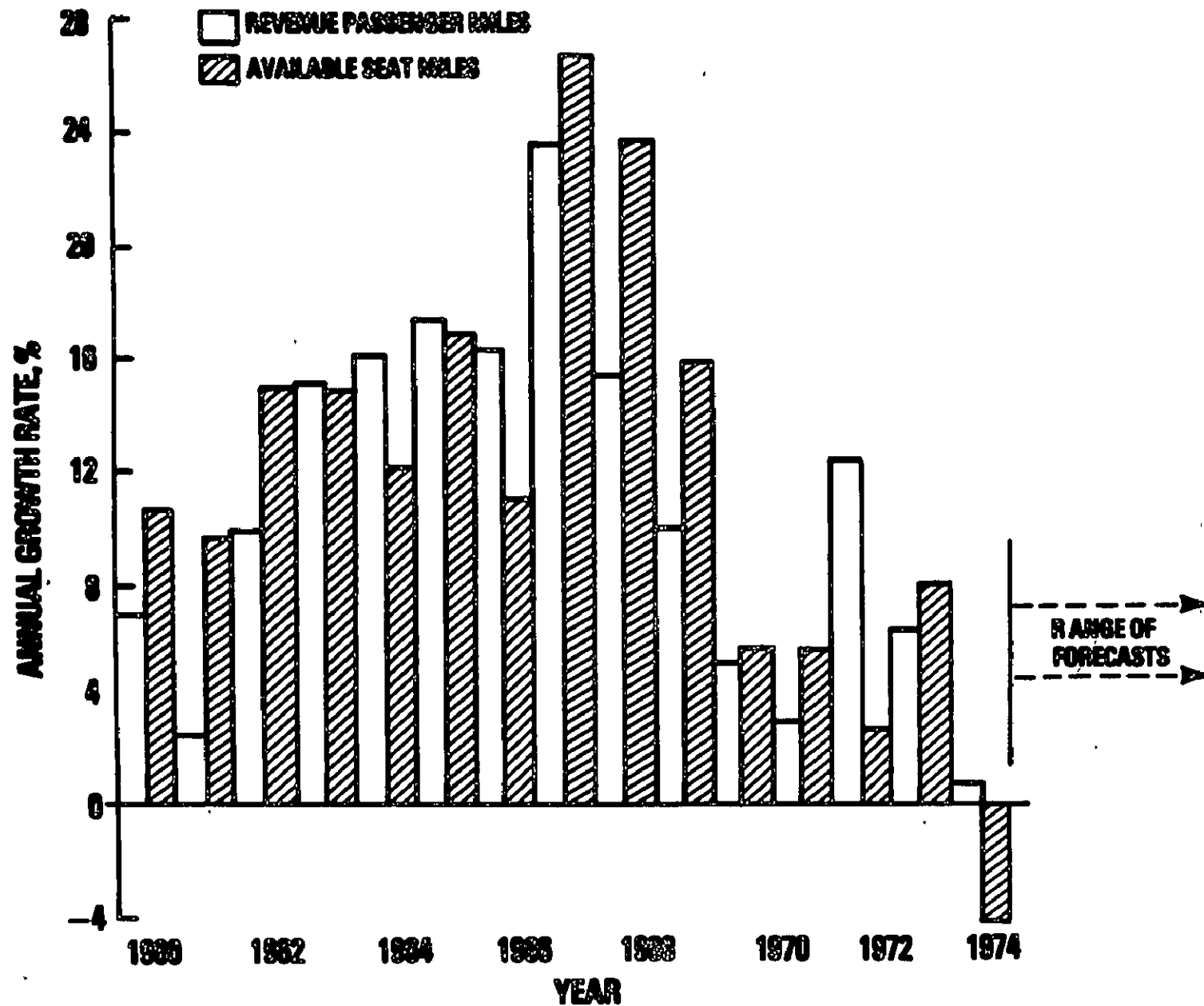


FIGURE 57

AVERAGE FUEL UTILIZATION BY AIRCRAFT TYPE *

<u>CATEGORY</u>	<u>AIRCRAFT</u>	<u>BARRELS/1000 RPM</u>	<u>PASS. MILES/GAL.</u>
3 OR 4 ENGINE WIDE BODY	B-747, DC-10, L-1011	0.991	24.0
4 ENGINE NARROW BODY	B-707, B-720, DC-8, CV-880, CV-990	1.403	17.0
3 ENGINE NARROW BODY	B-727	1.471	16.2
2 ENGINE NARROW BODY	B-737, DC-9	1.478	16.1

*BASED ON 1972 CAB DATA CORRECTED TO 55% LOAD FACTOR

TABLE 10.

TECHNOLOGY OPPORTUNITIES

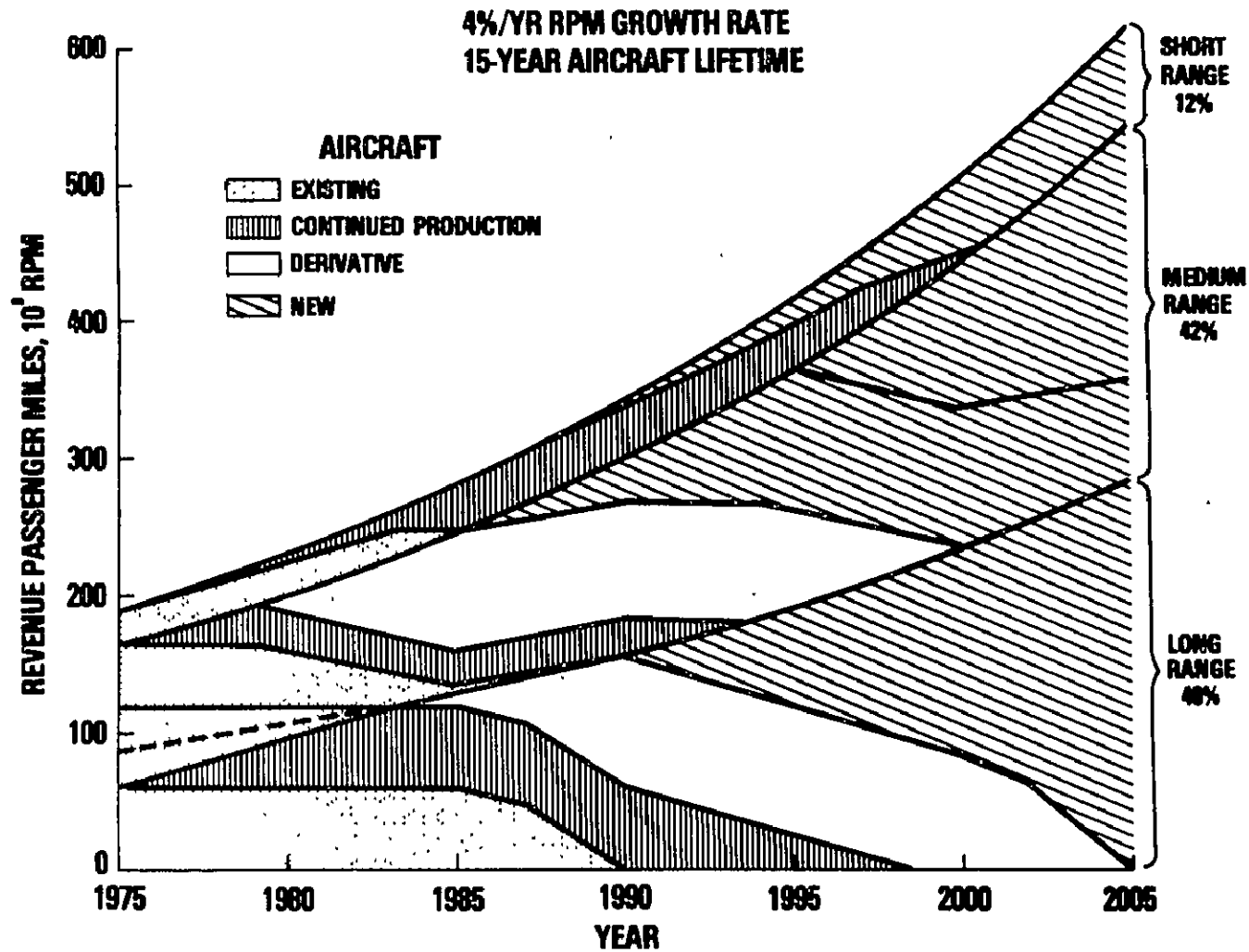


FIGURE 58

FORECAST FUEL USE DISTRIBUTION USING AVAILABLE TECHNOLOGY

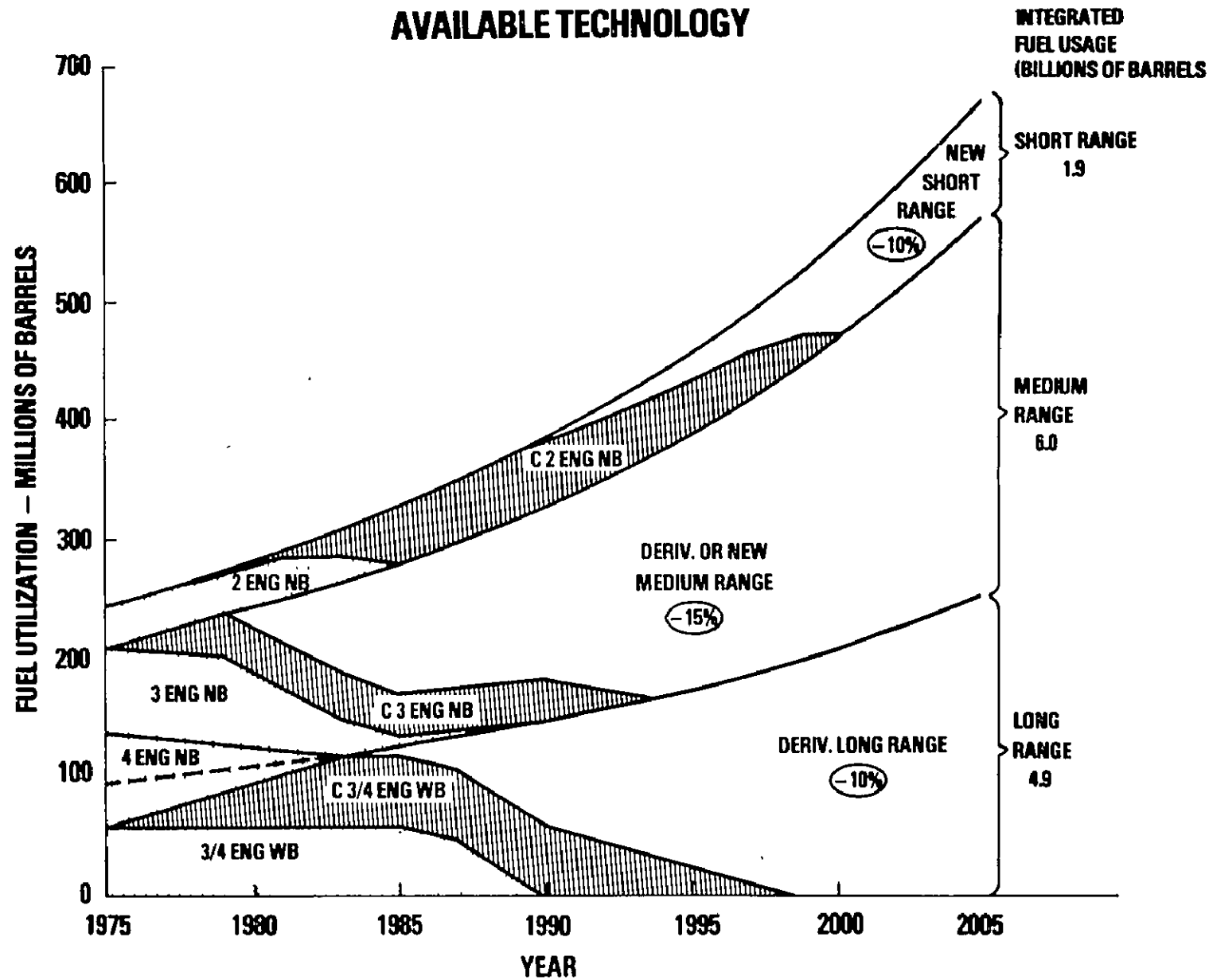


FIGURE 59

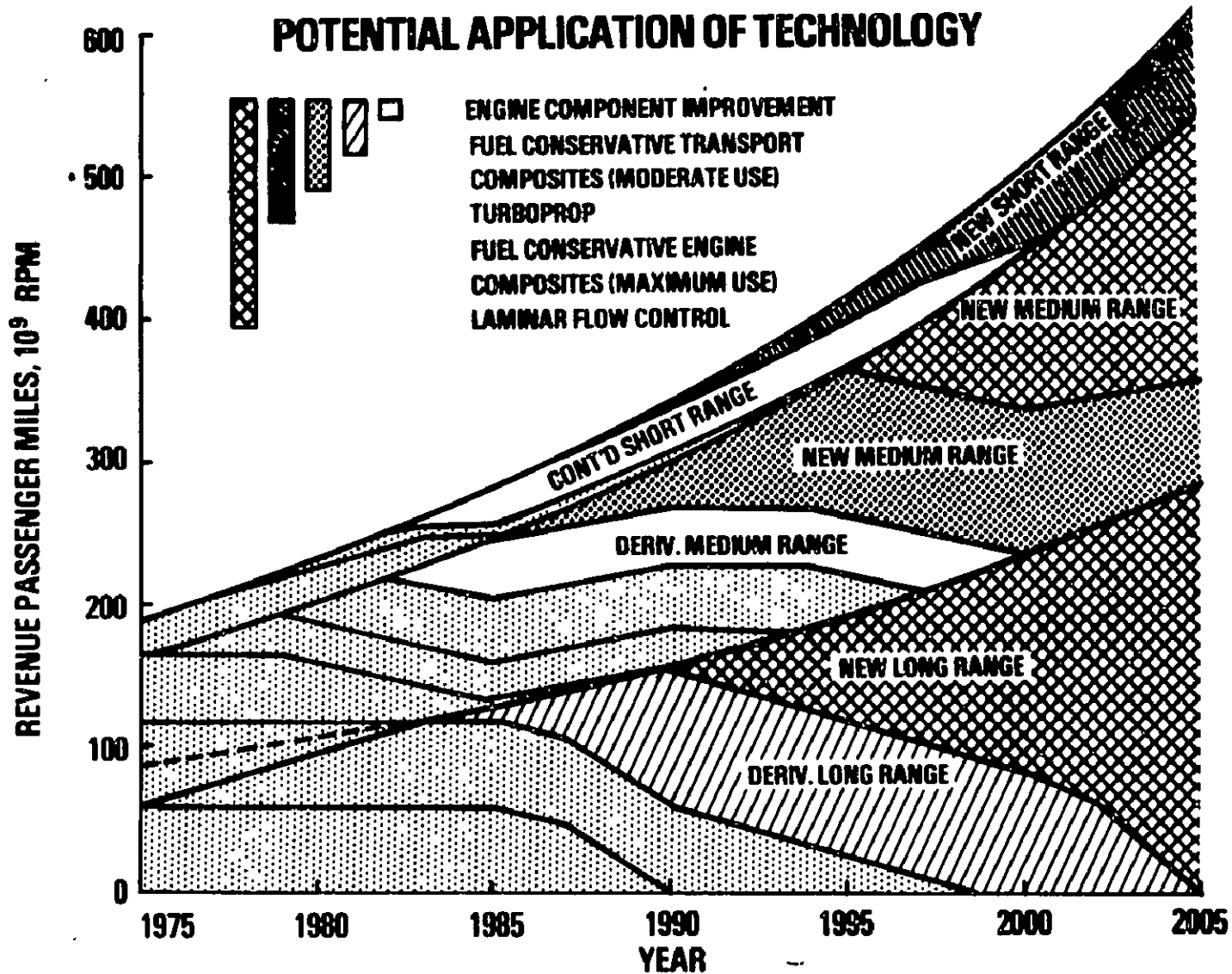


FIGURE 60

FORECAST FUEL USE DISTRIBUTION USING TECHNOLOGY IMPROVEMENTS

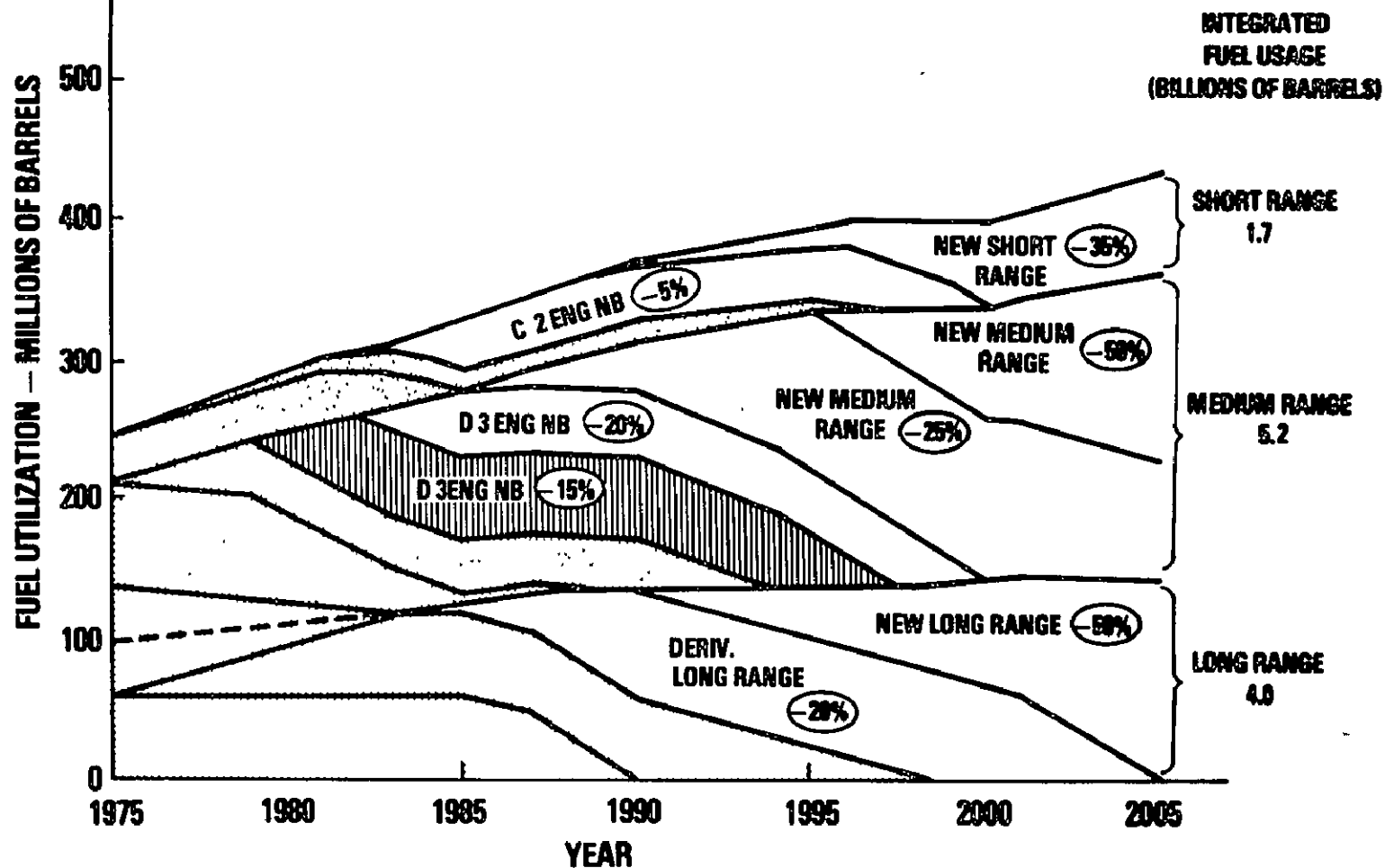


FIGURE 61

FORECAST TOTAL U.S. AIRLINE FUEL USE

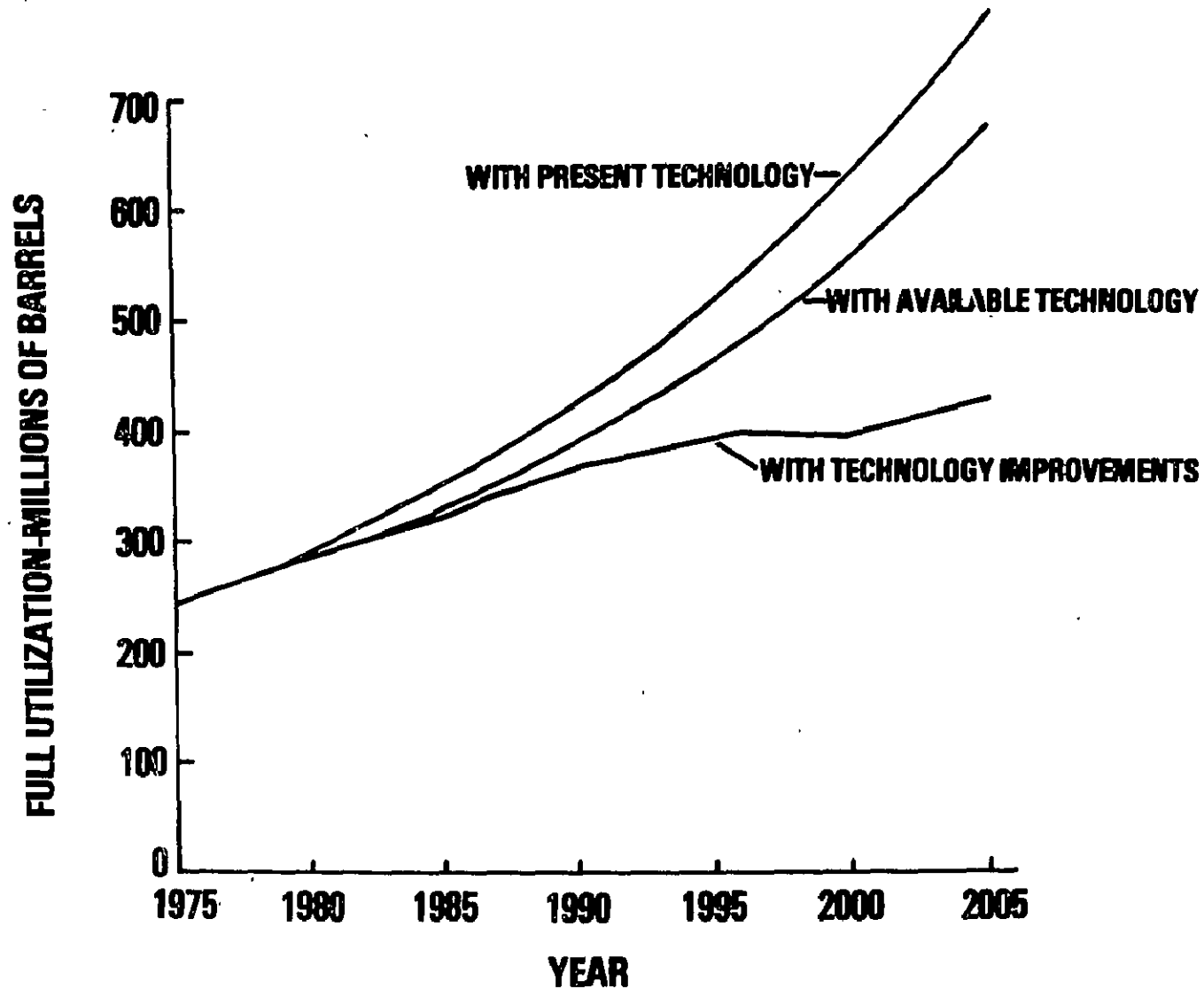


FIGURE 62

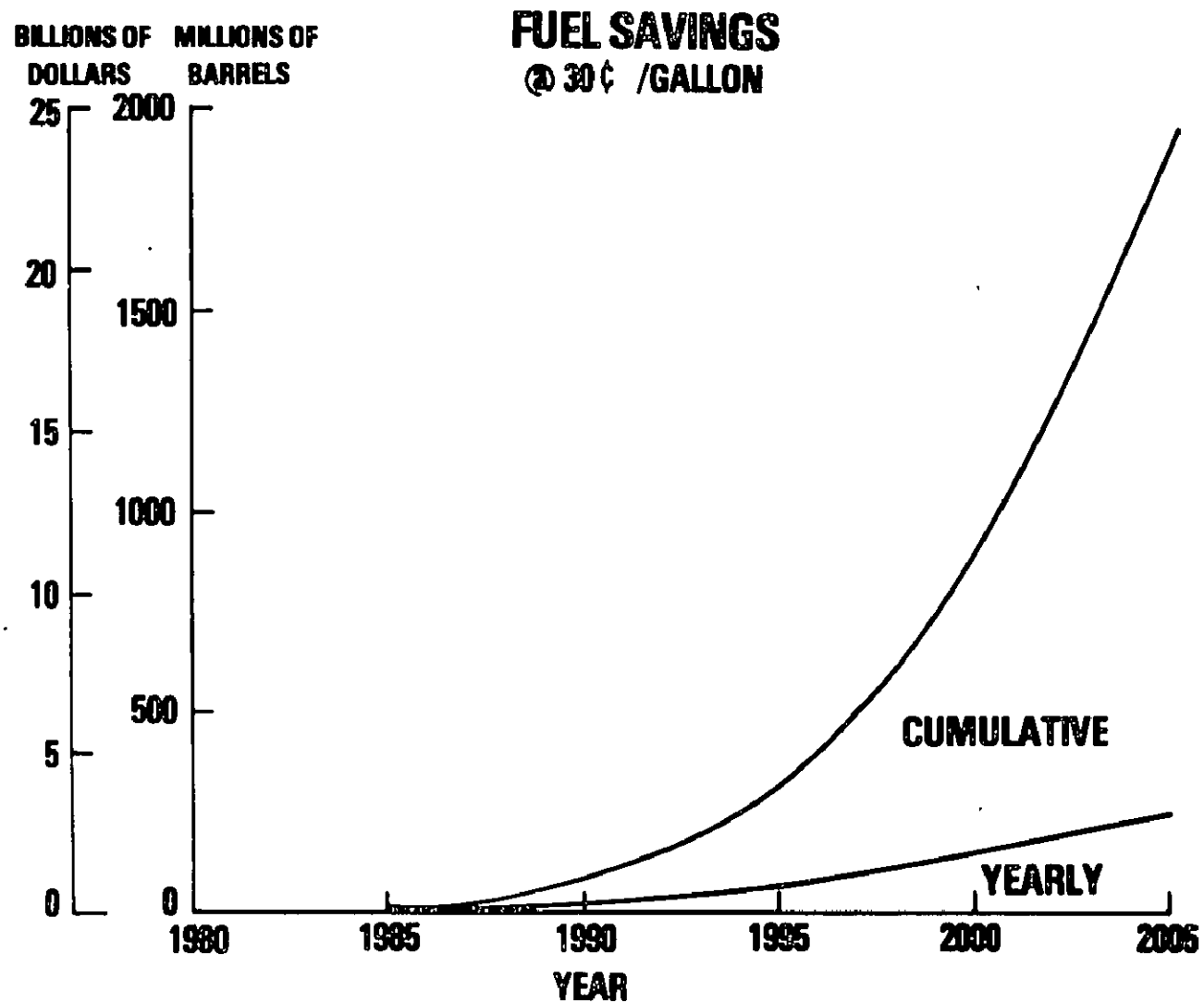


FIGURE 63

APPENDIX A

LETTER TO DR. JAMES C. FLETCHER
FROM SENATOR FRANK E. MOSS
AND SENATOR BARRY GOLDWATER

MR. E. MOSS, UTAH, CHAIRMAN
 WALTER E. STUBBS, JR., TENN., DEM.
 JOHN C. STENNIS, MISS.
 HOWARD W. CANNON, ILL.
 JAMES ABRAHAMSON, N. CAR.
 FLOYD K. HASKELL, CALIF.
 HOWARD M. METZENBAUM, OHIO
 SCH. WASH.
 BARRY GOLDWATER, ARIZ.
 CARL T. CURTIS, NEBR.
 LOWELL P. WICKER, JR., CONN.
 DEWEY F. BARTLETT, OKLA.
 JESSE HELMS, N.C.
 PETE V. DOMENICI, N. MEX.

ROBERT F. ALLMUTT, STAFF DIRECTOR

United States Senate

COMMITTEE ON
 AERONAUTICAL AND SPACE SCIENCES
 WASHINGTON, D.C. 20510

January 31, 1975

REPRODUCIBILITY OF THE
 ORIGINAL PAGE IS POOR

Dr. James C. Fletcher
 Administrator
 National Aeronautics and Space Administration
 Washington, D. C. 20546

Dear Dr. Fletcher:

As you know, the Committee has been reviewing the NASA
 Aeronautical Research and Technology program in detail. The highly
 competent support of Mr. Lloyd Jones and his staff in this review has
 been most helpful.

We were favorably impressed with many of the aeronautical
 projects aimed at achieving the NASA objective of "the preservation of
 the role of the United States as a leader in aeronautical science and
 technology."

In particular, we are impressed with those technology projects
 which could enable the United States industry to provide a new genera-
 tion of fuel-efficient commercial aircraft. Technologies have been
 identified with the potentiality of savings as high as 50 percent by 1985.
 The value of such technology should not be underestimated since potential
 benefits include both fuel savings -- perhaps approaching one million
 barrels of petroleum per day -- and increased international trade.

We feel that NASA, in consultation with industry, should
 consider establishing a clearly defined goal of demonstrating the
 technology necessary to make possible a new generation of fuel-efficient
 aircraft by a stated date. Such aircraft would have the same general
 operating characteristics as at present, would meet safety and environ-
 mental requirements, would be similar in cost, could be flying in the
 1980's, and would have a large improvement in fuel efficiency.


A-2

Dr. James C. Fletcher
January 31, 1975
Page Two

Adopting the type of goal we have in mind would require that you develop the program to achieve it in such a fashion that the technology transfer process is facilitated. The program which NASA develops should specify major milestones, percent of fuel savings to be achieved, and a description of the planned efforts and their cost.

We think it would be most appropriate that your initial response to this suggestion be included in the NASA presentation during the FY 1976 authorization hearings. It is our hope that the goal you establish will be one that is both feasible and challenging.

Sincerely,


Barry Goldwater
Ranking Minority Member


Frank E. Moss
Chairman

A-3

APPENDIX B

REPORT OF ADVISORY BOARD ON
AIRCRAFT FUEL CONSERVATION TECHNOLOGY

COMMENTS AND RECOMMENDATIONS
ON TASK FORCE PRELIMINARY PLAN

MAY 7, 1975

B-1



UNIVERSITY OF MISSOURI-ROLLA

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

Office of the Chancellor

210 Parker Hall
Rolla, Missouri 65401
Telephone (314) 341-4114

July 30, 1975

Dr. Alan M. Lovelace
Associate Administrator for
Aeronautics and Space Technology
National Aeronautics and Space
Administration
Washington, D.C. 20546

Dear Dr. Lovelace:

As a result of Advisory Board meetings held on May 7, 1975 and June 18, 1975, on NASA's proposed Aircraft Fuel Conservation Technology Program, the Advisory Board has prepared reports of its comments and recommendations relative to this program. These reports have been reviewed by each of the Board members and their comments have been incorporated.

As Chairman of the Advisory Board, I hereby submit these reports to NASA to use as you see fit.

Cordially,

A handwritten signature in cursive script, reading 'R. L. Bisplinghoff'.

Raymond L. Bisplinghoff
Chairman, Aircraft Fuel Conservation
Technology Advisory Board

RLB/1a

Handwritten initials 'B-1a' in a cursive script.

ADVISORY BOARD REPORT OF FIRST MEETING ON
AIRCRAFT FUEL CONSERVATION TECHNOLOGY

INTRODUCTION

On May 7, 1975, the Advisory Board on Aircraft Fuel Conservation Technology (membership list enclosed) met to review, criticize, and make recommendations on a preliminary NASA program plan for future work on aircraft fuel conservation technology. The plan was prepared by a Task Force of NASA personnel and representatives from DOD, DOT, and FAA, and was presented to the Board by Mr. James J. Kramer, Director of the Task Force. The plan was the result of extensive discussions with industry and the airlines. Considerable paring down of an initial list of suggested program elements had already been accomplished by the Task Force, however, some additional sizing of the plan downward is to be expected due to funding and manpower constraints. The plan was divided into specific technology sections on aerodynamics, propulsion, structures, active controls, and operations/avionics. Summary comments of the Board on the preliminary plan follow.

SUMMARY COMMENTS

Aerodynamics

- o Flight test of winglets by NASA on one aircraft to check out wind tunnel model results is endorsed. However, since the fuel savings benefits of winglets depend on the airplane to which they are applied, the airframe manufacturers will be required to sort out specific airplane systems aspects before a winglet retrofit could be accomplished.
- o NASA should expand work on the development of advanced analysis, design optimization methods, and criteria that will enable the airframe manufacturers to generate the "optimum" airfoil to satisfy their particular requirements. "Design-to" criteria, such as allowable

B-16

pressure gradients, should be established by NASA. NASA should direct more attention to the problem of applying transonic two-dimensional data and design criteria to three-dimensional wings. A firm substantiation of full-scale simulation techniques is required.

- o Propulsion system/airframe integration is recognized as an important area for NASA. Propulsion integration has the biggest potential payoff of the program elements discussed under advanced wing technology. Wind tunnel test techniques, including powered models, need to be more sophisticated.
- o Expanded work on laminar flow control is endorsed with emphasis on development of practical, maintainable and reliable structural systems. Decision on a research aircraft demonstration should await results of detailed design studies and wind tunnel studies.

Propulsion

- o NASA has a role in determining the sources of performance degradation of current engines. The main use of the results will probably be for future engine development. Economics will determine whether results will be applied to in-service engines.
- o Improvement of component performance of new production of current engine types is a useful area for NASA effort. Results will be useful to new engines as well.
- o There is no technology role for NASA in the 10-ton class of engines beyond the development of improved components. The use of these engines for retrofit, or for newly-designed aircraft, will be determined by economics. As a national position, capital investment to introduce these engines should be encouraged rather than greater expenditures for the purchase of foreign oil.

- o NASA should augment its basic and applied research programs directed toward improving the performance of aircraft engines so as to conserve fuel in flight and ground operations. Higher engine and engine installation efficiencies are required accompanied by increased engine durability and safety, and reduced engine noise and pollutant discharge. The Department of Defense should be advised of NASA's research programs and of any new engine developments or modifications that are being initiated to demonstrate research results so that undesirable duplication may be avoided:
- o In turboprops, NASA should work on propeller aerodynamics, structures and control systems. In addition, some preliminary engine and configuration airplane design studies should be done. System integration studies which focus on stage lengths, speeds, and altitudes which are compatible with current civil flight profiles need to be performed. Decision for a demonstrator aircraft must await results of this several year effort. Airline operators should be involved in the program to ensure that all operational questions are properly addressed.
- o Alternate fuels research is an important area currently addressed in both NASA and DOD programs. This work should be followed closely and the impact of alternate fuels on the technology requirements for aircraft fuel conservation should be assessed. No additional effort in this area is recommended at this time.

Structures

- o In-service flight tests of composite primary structures are strongly endorsed. Some experience can be gained from military programs but more government involvement is needed to ensure widespread use of composites in new civil aircraft

designs. Manufacturers see a big payoff and high probability of technical success but don't have adequate resources to build-up in-service confidence. Recommend additional FY 1976 and FY 1977 funding for composite wing construction.

Active Controls

- o Recognized as an important area for application to new aircraft designs but place low priority on expanding NASA effort beyond current program. Confidence in the feasibility and reliability is being gained from military programs and from non-flight critical systems on current civil aircraft. NASA should keep the FAA apprised of developments in active control system technology for their use in the certification of future aircraft designs which may use active controls.

Operations/Avionics

- o Although many important reductions in fuel use of current aircraft have already been achieved in airline transport operations, continued study of this near-term possibility for fuel conservation is required. To aid in establishing fuel conservative operating procedures for the future, NASA should join with FAA, DOD and airline representatives in identifying additional improvements to be made on all aspects of aircraft operations, including airways and approach control procedures, facilities, and equipment.
- o The current Terminal Configured Vehicle Program is endorsed. NASA should continue to work with the FAA to ensure that the technology can be implemented when ready.

General

- o The relative effort in each technology area is appropriate for the first 2-3 years, however, consideration should be given to increasing the level of funding in these years, particularly in the structures area.
- o Attention should be given to the development of a program plan to show that only some items will be carried through to hardware stage in the 10-year plan.
- o NASA is urged to emphasize program payoff in terms of the national economics considering improved balance of trade, increased U.S. jobs, and better export products rather than just airline economics.
- o NASA should consider integrating all fuel conservation technologies into an aircraft which demonstrates the benefits. This integration could be accomplished through a paper aircraft design and scale-model wind tunnel tests, as appropriate.

Raymond L. Bisplinghoff
Chairman

APPENDIX C

REPORT OF ADVISORY BOARD ON
AIRCRAFT FUEL CONSERVATION TECHNOLOGY

COMMENTS AND RECOMMENDATIONS
ON TASK FORCE REVISED PRELIMINARY PLAN

JUNE 18, 1975

C-1

ADVISORY BOARD REPORT OF SECOND MEETING ON
AIRCRAFT FUEL CONSERVATION TECHNOLOGY

INTRODUCTION

On June 18, 1975, the Advisory Board on Aircraft Fuel Conservation Technology met to review NASA's revised program plan for a ten year effort on technology for reduced aircraft fuel consumption. The plan reflected recommendations made by the Advisory Board and the Center Directors of NASA's four aeronautical research centers on a preliminary plan presented to the Board on May 7, 1975. The plan was developed by a Task Force of NASA personnel and representatives of DOD, DOT, and FAA. Dr. James J. Kramer, Director of the Task Force, presented the plan to the Board as seven specific technology elements: Current Engines, Fuel Conservative Engine, Turbo-props, Winglet Flight Test, Fuel Conservative Transport, Laminar Flow Control, and Composite Primary Aircraft Structures. The Board's summary comments on these seven elements and general comments follow.

SUMMARY COMMENTS

Current Engines

- o This is a high priority technology item with possibly the greatest potential for near-term fuel savings of the seven technology items discussed. The main application of the results will be for new production of current engine types and future engines, however, the possibility of application to in-service engines should not be dismissed. This application will certainly be considered by the airlines in terms of economic tradeoffs.
- o Although air transportation consumes a small percent of the total petroleum fuel in today's operations, its growth potential will be severely impacted by future energy constraints. Since a one percent fuel savings translates to approximately \$50 million

C/A

per year in today's market for U.S. domestic operators, it is a significant item and will grow more significant with time. Emphasis should be placed on every opportunity to make design/technology improvements for lower specific fuel consumption. The component technologies identified, namely mixer nacelles, compliant seals, tip clearance control, and blade shapes should be stated as typical examples recognizing that other propulsion system components may be identified as contributing to performance improvement and reduction of degradation in service.

- o FY 76-78 funding of \$11 million identified for this effort is inadequate and should be increased. In addition, the distribution of funding between component technology and engine tests should be modified to reflect the fact that much component work is best accomplished on an engine. Engine tests should receive more of the funding and should begin earlier.
- o Because of the importance of fuel conservation, emphasis should be placed on understanding the sources of performance degradation. NASA should consider diagnostic testing and evaluation of in-service engines as part of this effort. However, it should be recognized that the engine companies and the airlines have already conducted some diagnostic tests. Results of these tests should be used as a starting point for a NASA program in this area.

Turboprops

- o The high potential fuel savings for turboprops and the lack of development by industry justify early exploratory efforts by NASA. An \$8 million three-year effort to determine propellor efficiency at increased cruise Mach numbers and to study potential engine/airframe configurations is recommended.

- o The necessity and desirability of follow-on phases which would include complete propulsion system testing and perhaps a research aircraft is not clear at this time. Decisions for the follow-on phases (estimated at a total of \$98 million) will depend on results of the propeller aerodynamic tests, configuration studies, and the operating cost (including fuel) estimates of advanced turboprops as compared to advanced turbofans.
- o The program description should indicate engine development efforts prior to engine testing. It is likely that existing core engines would be suitable for flight testing but power turbines, gearsets, and structures would have to be provided.

Fuel Conservative Engine

- o Early-year funding increments for advanced fuel-conservative engines appear to be inadequate, however, a more complete description of the on-going fuel-related propulsion efforts is required before this conclusion can be drawn.
- o It may be that the commonality is decreasing between gas generator requirements for high performance military engines and for high bypass turbofans. If so, NASA has an important role in advanced gas generators for fuel conservative engines.
- o Although more fuel-efficient engines are important for future aircraft, their impact will not be felt until later because their introduction in service is not likely until 1985-1990. However, some of the technology for these new engines will undoubtedly point the way for further improvements in later models of current high-bypass turbofans produced in the 1980's.

- o There needs to be a stimulation of new ideas to bring about revolutionary advances in future engines. However, important evolutionary gains will continue to be made which have a high probability of success in providing 15% fuel savings compared to today's high-bypass turbofans. It should be borne in mind that changes which result in lower initial fuel consumption at the expense of more rapid deterioration of performance with service life are not desirable.

Winglet Flight Test

- o This effort is judged to have the lowest priority of the seven technology items discussed.
- o It is believed that while calculations and wind tunnel tests may indicate potential gains, limitations in the calculations with regard to real flow effects such as viscosity, separation, and Reynolds number effects, as well as wind tunnel test limitations (transonic wall effects, for example) suggest that flight test validation of a specific installation by NASA may be necessary as a proof of concept demonstration. However, flight tests may be of limited value since the application of winglets would be different for each aircraft type. For some aircraft, a wing-tip extension would be preferred over winglets.
- o Support of the Air Force winglet program by NASA should be continued. NASA is encouraged to provide support for flight tests of winglets on an Air Force airplane if such a program is funded by the Air Force. An Air Force flight program on a military aircraft may not necessarily provide the same technology validation data as a NASA program on a civil transport.

Fuel Conservative Transport

- o The content and resource requirements of this program are considered appropriate. Early-year effort should emphasize advanced wing technology.

- o The necessity of a research aircraft flight test which incorporates a large number of fuel-saving technologies is not at all clear. If high-risk technology items are identified in the early-year efforts, then it may be appropriate for NASA to demonstrate those technologies through selected flight tests. However, a research aircraft flight test which incorporates a large number of fuel saving technologies in one configuration is not encouraged.
- o Either as a part of this program or as a separate technology task, NASA should consider the feasibility of identifying and reducing sources of drag on existing aircraft as a technique for near-term fuel savings.

Laminar Flow Control

- o Because of the significant fuel savings potential of laminar flow control, the lack of industry effort in this area, and its high risk, NASA is encouraged to pursue exploratory development of a practical, reliable and maintainable laminar flow control system for future aircraft. The first phase, three-year resources of \$7 million identified for this effort are appropriate.
- o If the practical system development proves feasible, a modified research aircraft flight demonstration and/or an in-service flight evaluation may be required to answer reliability and maintainability questions. Inputs from airline operators should be obtained on the subjects of reliability and maintenance.

Composite Primary Aircraft Structures

- o Because of the high probability of the use of composites in future aircraft and the lack of sufficient industry resources for building

reliability confidence in a timely way, the Board strongly endorses NASA's program to obtain in-service life experience on composite vertical tail and wing components.

- o Additionally, NASA is strongly encouraged to include in-service life testing of a composite fuselage in its program. Further study is required to determine to what extent fuselage sections can be used to develop confidence in the feasibility of entire fuselages made from composites.
- o Emphasis on the cost reduction aspects of composites in both design and tooling as well as fabrication and assembly should be an integral part of the NASA program. If this point is not stressed, incorporation of advanced composite structures into service will lag due to the economic risks, even if the technical aspects are well understood.

General

- o The total program funding requirements identified for the first three years (FY 76-78) are inadequate compared with the gravity of the fuel cost and availability problem and the reductions in aircraft fuel consumption which are possible through a vigorous technology program.
- o Although assignment of priority to the seven technology elements was not accomplished by the Board, the early year (FY 76-78) relative funding distribution among propulsion, aerodynamics, and structures elements was judged appropriate.
- o High cost, follow-on phases of the program, especially flight demonstrations, should be viewed as future decisions dependent on successful results from the exploratory, first phase efforts. As a general philosophy, NASA should support proof-of-concept programs and not be involved in prototype demonstrations.

- o NASA is encouraged to conduct an in-depth economic modeling study involving economists, airline operators, and engine and airframe manufacturers to develop the total costs and benefits to the nation of a vigorous research and development program on aircraft fuel conservation technology.
- o NASA is encouraged to continue, and accelerate if possible, its current program on terminal configured vehicles and to continue to work closely with the FAA in identifying additional technology requirements for the development of more fuel-efficient operational procedures.
- o It is recommended that NASA take an active role in making known to the Administration and the Congress the fuel-savings potential of the ten-ton class of engines and the economic situation which is delaying their introduction into service.
- o NASA is urged to keep the FAA informed of progress on aircraft fuel conservation technology developments which will ultimately require FAA certification for airline passenger service.

Raymond L. Bisplinghoff
Chairman

